A SATELLITE AGNOSTIC APPROACH TO QUANTIFYING HAIL DAMAGE SWATHS ACROSS THE CENTRAL UNITED STATES AND OTHER AGRICULTURAL REGIONS

Jordan R. Bell[1], Andrew L. Molthan[1], Christopher R. Hain[1], Franz J. Meyer[2], Christopher J. Schultz[1], Nicholas J. Elmer[3]

[1]Earth Science Branch, NASA Marshall Space Flight Center, Huntsville, Alabama, USA
[2]Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska, USA
[3]NASA Postdoctoral Program, NASA MSFC, Huntsville, Alabama, USA

ABSTRACT

Intense thunderstorms can bring damaging winds and large hail to agricultural regions during the prime growing season. In certain cases, large swaths of damage from the wind and hail are left behind and visible to satellite remote sensing instruments. Often times, Earth observing optical remote sensing from low to high spatial resolutions are able to view these damaged swaths. With the large number of moderate to high-resolution instruments in orbit, these damaged areas have potential to be viewed daily. However, during the prime growing season, clouds frequently block the viewing of the land surface by these optical instruments. Space-borne synthetic aperture radar (SAR) instruments allow for the viewing of the land surface in most weather conditions, but instead measure backscatter as opposed to optical sensors measuring reflected or emitted radiation. Additionally, the number of SAR instruments with free and open data lags behind the number of optical sensors. This paper describes the development of a methodology that attempts to characterize hail damaged swaths, through independent use of multiple optical and SAR platforms. This satellite-agnostic approach will focus statistical analysis by comparing undamaged areas to suspected damaged areas by using commonly derived indices from optical instruments and SAR backscatter from multiple polarizations.

Index Terms—remote sensing, optical, synthetic aperture radar, vegetation, hail, damage, agriculture, satellite agnostic

I. INTRODUCTION

During the prime growing season, agricultural areas are exposed to a variety of threats. Among them, damaging winds and large hail can cause various degrees of damage and/or destroy the impacted agricultural areas. Occasionally, these intense thunderstorms can leave behind a long-track of damage from the wind and hail known as hail damage swaths. These hail damage swaths can be upwards of tens of kilometers long and 7-12 kilometers wide [1].

The damaged areas experience abrupt changes to the surface as the intense thunderstorms strip the vegetation and topple stalks, which can lead to farmers having to clear areas of damage [2]. Hail damage swaths have been analyzed going all the way back to the 1960s and 1970s utilizing aircraft and thorough ground surveys [3]. Recent analyses of the hail damage swaths have been done using remote sensors aboard space-borne instruments. The damaged areas when viewed through optical instruments experience changes in reflectance characteristics, especially prevalent in the visible and near-infrared wavelengths [3, 4, 5, 6]. Sharp gradients between the degrees damaged vegetation and bare soil areas and undamaged healthy vegetation have revealed gradients of warmer land surface temperatures exist [7]. Synthetic aperture radar (SAR) was evaluated for utility in complementing optical data, as well understanding how the damaged and undamaged were observed by the SAR instrument [8].

In this study we explore methods applicable to data from both the optical and SAR instruments for the development of a satellite-agnostic approach to detecting and quantifying damage to agricultural areas caused by damaging winds and large hail. A satellite-agnostic approach allows for data from either optical or SAR instruments to be implemented into a workflow that will yield the same final product(s) in quantifying the damage.

II. DATA & METHODOLOGY

This study leverages a large number of instruments from the Earth Observation System fleet, international partners, and commercial industry. These sensors have a varying range of temporal and spatial resolutions. MODIS and VIIRS allow for multiple daily viewing options of the damaged areas, but at coarse resolutions, which provide only rough outlines of the varying degrees of damage. Landsat-8 OLI, Sentinel-1 A/B and Sentinel-2 A/B have higher spatial resolutions, roughly field scale, but have longer temporal resolutions. However, a combination of these three sensors provides a 1-3 day temporal resolution. Commercial satellites like those from Planet Labs provide the highest spatial resolution as well as a temporal resolution similar to that of the moderate spatial resolution instruments. Table 1 highlights the sensors used in this study as well as their spatial and temporal resolutions.

Table 1. Sensors used in development of this satellite-agnostic approach. A large number of sensor have multiple spatial resolutions depending on what spectral bands are being used. This methodology utilized the best spatial resolution that the sensor offered.

Sensor	Best Resolution (m)	Temporal Resolution
GOES ABI	500	Sub-hourly
MODIS	250	Daily
VIIRS	375	Daily
Landsat-8 OLI	30	16 day
Sentinel-2A/B	30	5 day
Sentinel-1A/B	30	12 day
Planet	3	Variable

Common vegetation indices that take advantage of spectral bands found on all the optical instruments, such as the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) were created for analysis. These indices provide information on the health agricultural areas and can easily discern changes in the vegetation. For the analysis from the SAR instrument, the both the co- and cross-polarization backscatter data were used. SAR's backscatter provides information about the SAR signal's interactions with the detected objects, which in this case is the state of the vegetation on the surface. Ancillary datasets such as the Crop Data Layer, an annual 30 m crop-identification product from the U.S. Department of Agriculture [9]. The CDL was used to identify prominent crop types in the impacted regions that would be compared for analysis. A radar derived hail estimation product, the Maximum Estimated Size of Hail (MESH), is another ancillary dataset used to differentiate perceived damaged and undamaged areas from one another [10].

For each detected hail damage swath, a domain is set up for the region that encompasses the potential impacted areas and areas that were not impacted by the damaging hail. All satellite derived products (NDVI, EVI, and SAR backscatter) that are acquired, are clipped to this domain as are the ancillary datasets. The ancillary datasets are also resampled to the same spatial resolution as the various observed satellite products.

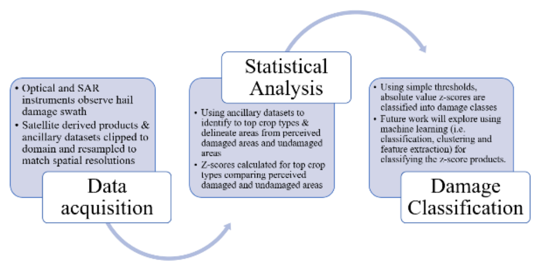

Figure 1. Graphical representation of methodology.

A new land-classification mask is created using the CDL to identify the top four crop type/land classification types. All the remaining crop types/land classifications are put into an 'other' class. Open water and urban areas are masked out from classifications. A second mask was created using the MESH data to discern the perceived damaged areas from the undamaged areas. A simple MESH value threshold (1.27 cm (0.5 in.) was used to discern the two areas from one another. Using the satellite dataset, the crop type/land classification mask and the MESH mask a statistical analysis (z-score) was calculated for the domain. The z-score was calculate comparing similar crop type/land classifications between the undamaged and damaged areas (Equation 1):

$$z = \frac{x - \mu_c}{\sigma_c}$$

where x is the optical index value or SAR backscatter of the a pixel of the same crop type/land classification across the domain, μ_c is the mean of all the undamaged pixels (MESH < 1.27 cm (0.50 in) of the same crop type/land classification, and σ_c is the standard deviation of all the undamaged pixels of the same crop type/land classification.

Figure 2. MODIS True Color composite observed on 11 August 2018.

The outcome of the calculate presents a z-score product across the event domain that shows some variability across the undamaged areas, but an identifiable swath of damage with more extreme z-score values becomes present (Figure 3). This z-score product can then be classified into damage classes. In order to use uniform z-scores between the optical and SAR datasets, the absolute values of the z-score products are used to classify the various damage classes. Table 2 is describes the simple thresholds that are used that make up the various damage classes.

Table 2. Damage classification thresholds for z-score product.

Damage Class	z-score Threshold
0	$z < 1.00$
1	$1.00 \leq z < 2.00$
2	$2.00 \leq z < 4.00$
3	$4.00 \leq z < 6.00$
4	$z \geq 6.00$

III. CASE STUDY

On 28 July 2018, intense thunderstorms moved through east-central Nebraska bringing with them 26.8 ms^{-1} (60 mph) winds and observed hail sizes ranging from 2.54 to 7.62 cm (1.0 to 3.0 in.) resulting in a hail damage swath that was estimated to be ~41 km (25 miles) long and ~8.5 (5 miles) km wide (Figure 3).

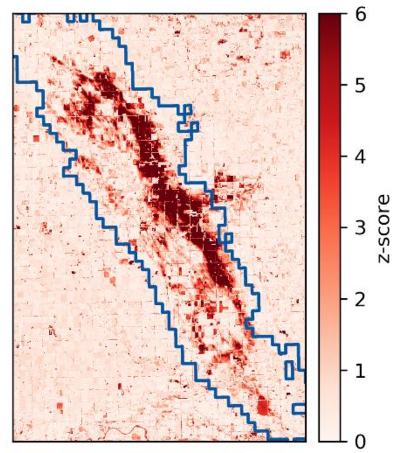

Figure 3. Example of z-score product for hail damage swath prior to classifying into damage classes. Blue line represents MESH threshold (1.27 cm, (0.5 in.)) separating perceived damaged areas from undamaged areas.

By mid-August a wide range of sensors had been able to observe the hail damage swath, including Landsat-8 and Sentinel-1. Using data from five different sensors, the z-scores for each sensors were calculated. Figure 4 shows the comparisons of z-scores calculated for imagery that was acquired in mid-August 2018. In addition to an increase in detail due to an increase in spatial resolution in the various observations, it was noted that the Sentinel-1 acquisition which a large number of the calculations were positive z-scores as opposed to negative z-scores that were observed in the optical data, that has been noted previous work [8].

IV. CONCLUSION AND FUTURE WORK

The development of a satellite-agnostic approaching to identifying and determining the various degrees of damage in and around hail damage swaths provided in this paper. This approach uses commonly derived vegetation indices from optical remote sensing instruments and dual-polarization backscatter from SAR instruments to find a way to identify the damaged areas and then provide quantitative information on the degrees of damage. One case study is presented here discussing the strengths and limitations discovered to date about the development of this methodology. Future work will focus on developing more automated ways (i.e. clustering, machine learning, and feature extraction) to classify the various degrees of damage.

IV. REFERENCES

[1] E. M. Frisby, “Hailstorms of the upper Great Plains of the United States”, *J. Applied Meteorology*, 2, 759-766.

[2] S. Changnon and N. Barron, “Quantification of Crop-Hail Losses by Aerial Photography”, *J. Applied Meteorology*, 10 (1), 86-96.

[3] G. J. Jedlovec, U. Nair, and S. L. Haines, “Detection of storm damage tracks with EOS data”, *Wea. Forecasting*, 21, 249-267.

[4] K. Gallo, T. Smith, K. Jungbluth, and P. Schumacher, “Hail swaths observed from satellite data and their relation to radar and surface-based observations: A case study”, *Wea. Forecasting*, 27, 796-802.

[5] A. L. Molthan, J.E. Burks, K.M. McGrath, and F.J. LaFontaine, “Multi-sensor examination of hail damage swaths for near real-time applications and assessment”, *J. Operational Meteorology*, 1 (13), 144-156.

[6] J. R. Bell and A. L. Molthan, “Evaluation of Approaches to Identifying Hail Damage to Crop Vegetation Using Satellite Imagery”, *J. Operational Meteorology*, 4 (11), 142-159

[7] Parker, M. D., I. C. Ratcliffe, and G. M. Henebry, 2005: The July 2003 Dakota hailswaths: Creation, characteristics, and possible impacts. *Mon. Wea. Rev*., 133, 1241–1260

[8] J. R. Bell, E. Gebremichael, A. L. Molthan, L. A. Schultz, F. J. Meyer, C. R. Hain, S. Shrestha, and K. C. Payne, “Complementing Optical Remote Sensing with Synthetic Aperture Radar Observations of Hail Damage Swaths to Agricultural Crops in the Central United States”, *J. Appl. Meteor. Climatol*. (In-review).

[9] Boryan, C., Yang, Z., Mueller, R., & Craig, M. (2011). Monitoring US Agriculture: the US Department of Agriculture, National Agricultural Statistics Service, Cropland Data Layer Program. *Geocarto International*, 26 (5), 341-358.

[10] Witt, A., M. D. Eilts, G. J. Stumpf, J. T. Johnson, E. D. Mitchell, and K. W. Thomas, 1998: An enhanced hail detection algorithm for the WSR-88D. *Wea. Forecasting*, 13 (2), 286–303.

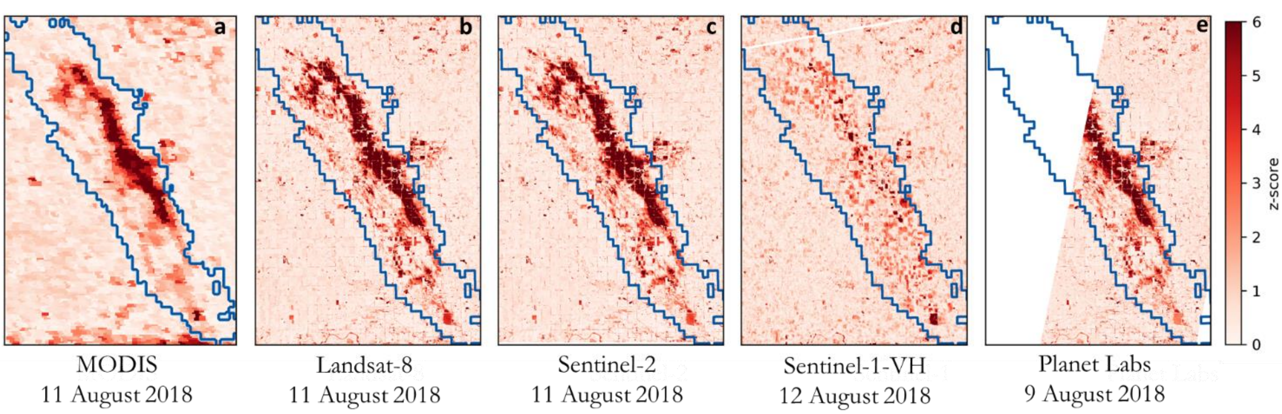

Figure 4. Comparison of various optical instrument and SAR z-scores calculated in mid-August for the 28 July 2018 intense thunderstorm event. a) MODIS absolute z-score from 11 August 2018, b) Landsat-8 absolute z-score from 11 August 2018, c) Sentinel-2 absolute z-score 11 August 2018, d) Sentinel-1 absolute z-score from 12 August 2018, and d) Planet Labs absolute z-score from 9 August 2018.