Correlation of Polarimetric Radar Hail Signature with MODIS Satellite Ground Truth Data

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Abstract

This Research Experience for Undergraduates (REU) project seeks to determine whether a correlation between polarimetric radar hail signature and satellite damage data exists. The polarimetric CSU-CHILL radar and Moderate Resolution Imaging Spectroradiometer (MODIS) data from the Terra satellite were used. First, two hailstorms were identified. The first hailstorm showed low H_{DR} values and damaged younger crop, while the second showed larger likelihood of sizable hail. The Normalized Difference in Vegetation Index (NDVI) calculated from MODIS data was used to determine changes in the satellite reflectance data over the path of the storms, which could then be correlated with crop damage. The H_{DR} and NDVI data will then be compared to the Storm Prediction Center's (SPC) storm reports, and photographs taken after the storms to insure damage was caused by hail. Due to the diverse land use in north and northeastern Colorado, it was found H_{DR} values must reach a certain threshold before crop damage may be detected by the NDVI method.

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Introduction

The purpose of this Research Experience for Undergraduates project is to identify a possible correlation between polarimetric radar hail signatures and satellite damage data. During the warm season in the United States, millions of dollars in crops are lost every year to hail damage. Since hail is a major contributor to crop loss in the Midwest, remote sensing of hail in a convective storm has been attempted before and it had been a challenge since the 1950s.

Hail damage on crops has been an ongoing concern especially in the Midwest since hail damage is characterized by extensive aerial coverage, which is time consuming, costly, and personnel-dependent to investigate. The amount of damage caused by hail varies depending on hail size, crop type, plant maturity, and time left in the season. The two storms studied varied greatly in hail size, plant maturity, and time left in the season. It will be interesting to compare the results and see if the radar and satellite data show similar trends in both storms. With the potential correlation between the radar hail signatures and the satellite data the researchers hope to create an useful tool to detect hail damage that can be used to access crop damage.

The data

The CSU-CHILL radar as well as the MODIS data from the Terra satellite will be used to study the two hailstorms. After the satellite data is acquired, the researchers used a differentiating method to determine if there was a change in the reflectance data over the path of the storms. The reflectance change will be used to map the extent of the damage that was caused by the storms by showing a change in photosynthesis activity.

This will then be compared to storm reports, and photographs taken after the storms to insure the actual damage caused by the storm.

Project Description

The storms

Two hailstorms that affected northern Colorado will be discussed in this report. The first hailstorm moved eastward through farmland located in unincorporated Weld County between Fort Collins, Colorado and the CHILL facility on June 19, 2002. This storm moved to east-southeast. The second crossed the South Platte River in Logan County near Sterling, Colorado on August 24, 2002. This storm moved to the southeast.

Figue 1: The area of of research. The city of Denver is in the southwestern (bottom left corner) of this map. The June 19, August 24 and the Chill radar are represented with symbols.

The area of study with the storm tracks can be seen on figure 1.

In the August case, hail caused considerable crop damage in irrigated fields along the Platte River valley. An example of this extensive crop loss can be seen on figure 2.

Radar and satellite information

While the storms inflicted damage to the vegetation, they were being monitored by the dual-polarization CSU-CHILL radar. Dual-polarization radars emit vertical and horizontal polarized waves and receive those backscattered signals back. The radar data showed strong evidence of hail and large hail was reported in the area. More about the hail signature will be explored in the literature review section of this paper.

Figure 2 - Extensive crop damage was documented after the August 24, 2002 hailstorm

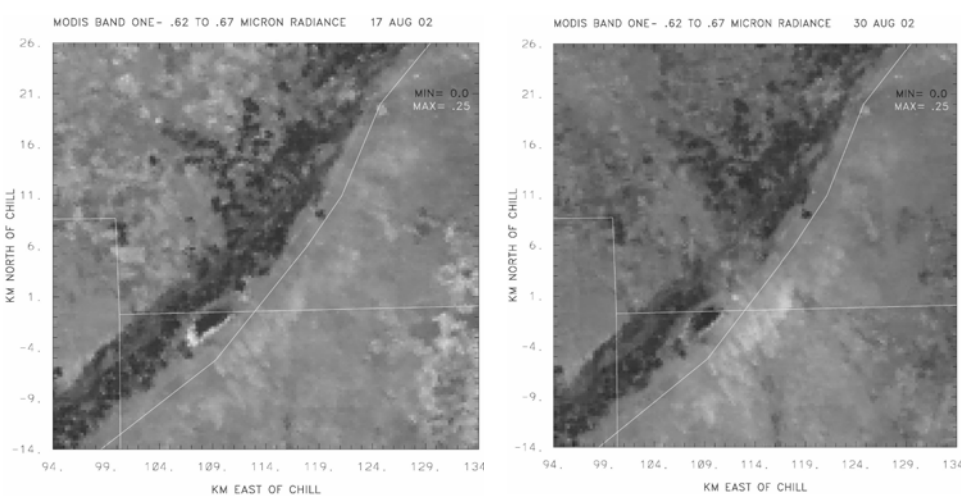


Figure 3: The august 24 hailstorm before and after satellite data (Visible red channel). A large difference can be noticed at the center of the image.

This damage was accessed by photographs directly after the hail storm had passed through the area. Preliminary temporal image differencing findings have also shown this damage produced detectable patterns in the MODIS data (see figure 3). The MODIS is able to acquire data in 36 spectral bands that, with some manipulation, obtains atmospheric, land, and ocean imaging. The finest resolution in this instrument is 250m. For more information about the MODIS, visit their website (http://modis.gsfc.nasa.gov/). Preliminary results for the August 24th hailstorm can be seen in figure 3.

The second case is known to have a lesser overall impact on the region. This hailstorm showed a less prevalent hail signature in the dual polarization CSU-CHILL radar. The hail reported was also smaller than the aforementioned case. The crop damage occurred earlier in the growing season, so some of the crop was able to recuperate from the storm. Since there was less damage in this case, researchers were not ale to detect this damage by differentiating MODIS information. Even after color coding the changes no path can be easily determined (see figure 4).

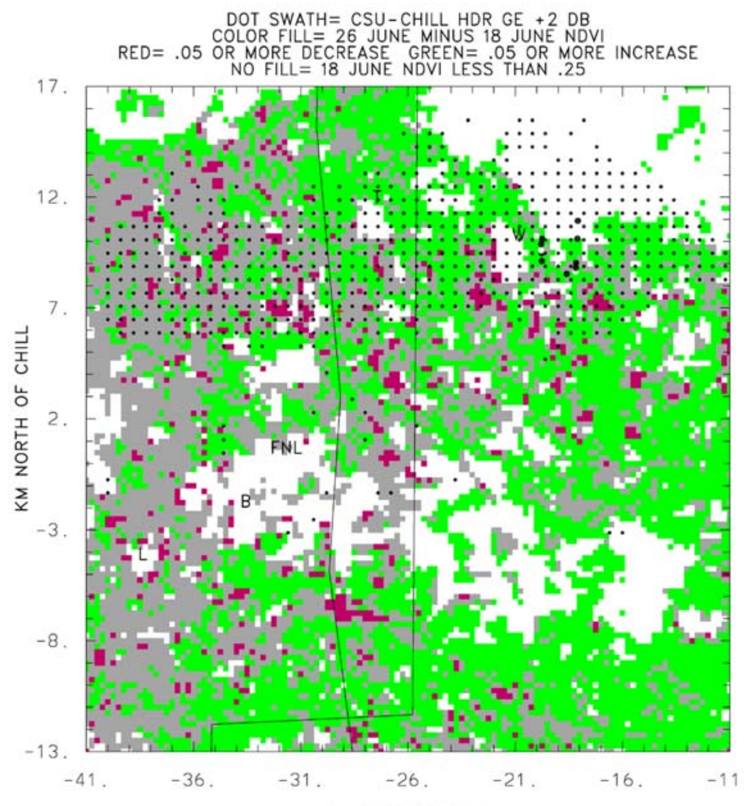


Figure 4: The changes in vegetation between the before and after dates. The dots represent the radar hail signature.

Literature Review

Remote sensing of damage caused by meteorological phenomenon has been extensively studied in recent years. Magsig (2000) found Landsat-7 data to be useful when identifying damage when the damage produced a significant change (or a signature) in the imagery. This hail streak signature was identified as early as the 1970s by Changnon when using aerial photos. Bentley et al (2002) also used Landsat data but they were aiming to identify wind and hail damage in agricultural fields. Hail streaks in crops were further studied by Henebry and Ratcliffe (2003) who used Advanced Very High Resolution Radiometer (AVHRR) imagery to identify persistent hailstreaks that are also observable by coarse spatial resolution imagery.

Scientists from as far away as Australia and Europe have also researched this topic. Apan et al. studied the effects of defoliation on spectral data and looked for the criteria a hailstorm must meet to be able to have its damage identified by satellite data. These researchers found that although there is a high correlation between defoliation and spectral data, external factors such as timing of acquisition of the data, equipment reliability, and inter-field variability shows that at this time this method should only be used as a guide instead of a main tool.

The study by Bentley as well as the study by Henebry and Ratcliffe used Normalized Difference Vegetation Index (NDVI) which highlighted abrupt changes in vegetation density by comparing before and after storm data. NDVI is a measure of vegetation intensity and in this report was found by calculated using MODIS channels 1 (620-670 nm) and 2 (841-876 mn). The magnitude of the NDVI data is a normalized ratio of the bands one and two calculated by:

$$NDVI = (Ch2-Ch1)/(Ch2+Ch1) \qquad (1)$$

This magnitude is related to the amount of photosynthesis observed in the vegetation and it ranges from 1 to -1, vegetated areas will generally have values larger then zero due to their high near-infrared and low visible reflectance (a characteristic of photosynthesis) (Kriegler et al. 1969). In this research project, researchers will seek a lower NDVI number in areas where hail had damaged the vegetation. NDVI will be used to map the extent of the damage that was caused by hailstorms.

Seliga and Bringi (1976) were the first people to explore the radar hail signatures we will be using in this research. What they found was differential reflectivity (Z_{DR}), which revolves around observations that when raindrops fall at terminal velocity they are no longer spherical but oblate spheroids. By looking at radar observations of horizontal and vertical cross sections, Z_{DR} was defined as:

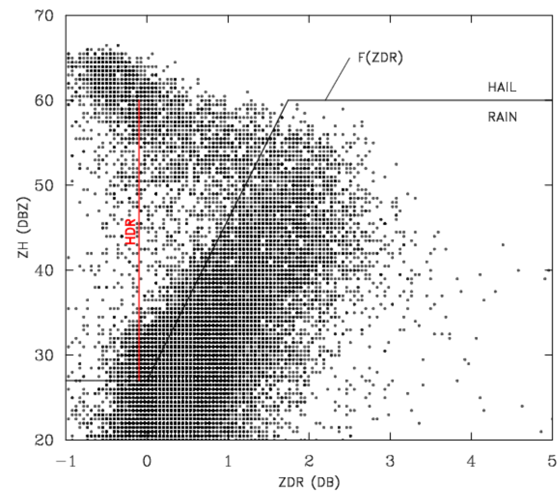
$$Z_{DR} = 10*\log(Z_H/Z_V) \qquad (2)$$

Differential reflectivity is negative when a droplet's major axis is close to vertical in the mean and positive when the major axis is close to horizontal in the mean (which makes sense with a droplet's oblate shape). Since hailstones are (for the most part) congruent in both axes, its Z_{DR} values are very near zero, although sometimes negative values are seen (Bringi et al. 1984). Z_{DR} values at and near zero were seen by the dual-polarization CSU-CHILL radar when the two storms studied in this paper were in progress.

The hail differential reflectivity parameter (H_{DR}) uses Z_{DR} in its calculations. H_{DR} was defined by Aydin et al. (1986) as:

$$H_{DR}=Z_H-g(Z_{DR}) \qquad (3)$$

Where, as explained above, Z_{DR}=0 or a value very near zero for hailstones. ($g(Z_{DR})$) was found with the use of disdrometer observations and it is used as the minimum threshold to prevent false hail interpretations. Positive H_{DR} values indicate the likelihood of hail and the larger the H_{DR}, the larger hail should be expected (Aydin et al. 1986). An example of this can be seen in Figure 5.



Example of CSU-CHILL Z_H and Z_{DR} gate data plotted in H_{DR} space (Aydin et. al, 1986). The data were collected in a 0.5 degree elevation angle PPI scan at 2343 UTC on 6 June 2003).

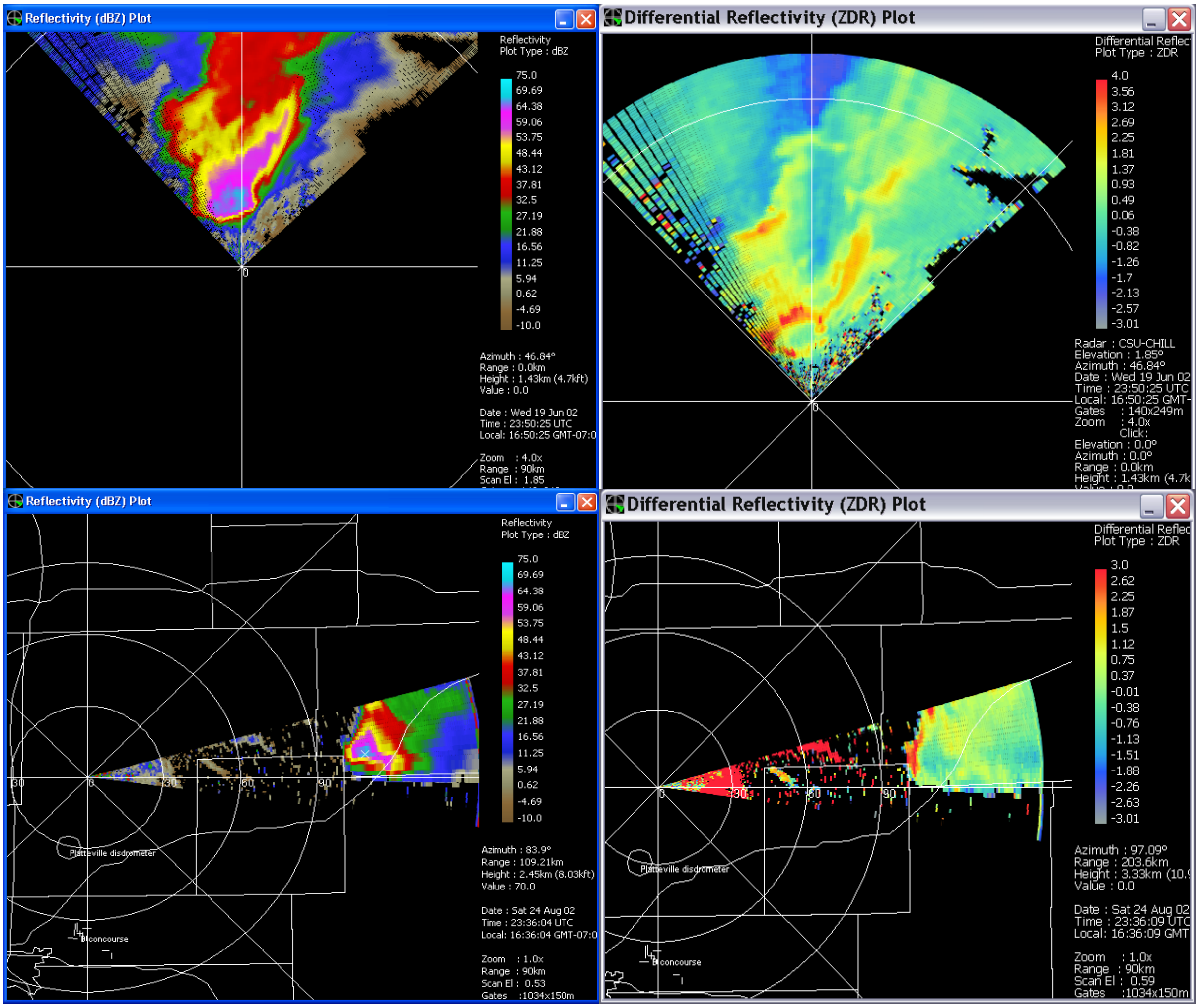


Figure 6: A V-CHILL display of the June 19th (top) and August 14th (Bottom) hailstorms. To the left are the dBZ plots and to the right the Z_{DR} plots. Notice the 70+ dBZ areas in both hailstorms and near zero Z_{DR} values.

Methodology

As mentioned above, both storms were monitored by the dual polarization CSU-CHILL radar when they passed through the study area. This data was processed in 2002 and was ready for analysis. This, among other radar data is available free of charge through V-CHILL (http://chill.colostate.edu/vchill/). Radar reflectivity data for the two storms can be seen in figure 6. These northern Colorado hailstorms were marked by high dB values and Z_{DR} values near zero.

Field photos were also taken after the storm to verify the extent of the crop damage. Lastly, detailed ground damage was recorded by Tracy Depue following the June 19, 2002 storm. This damage survey included GPS information and a detail account

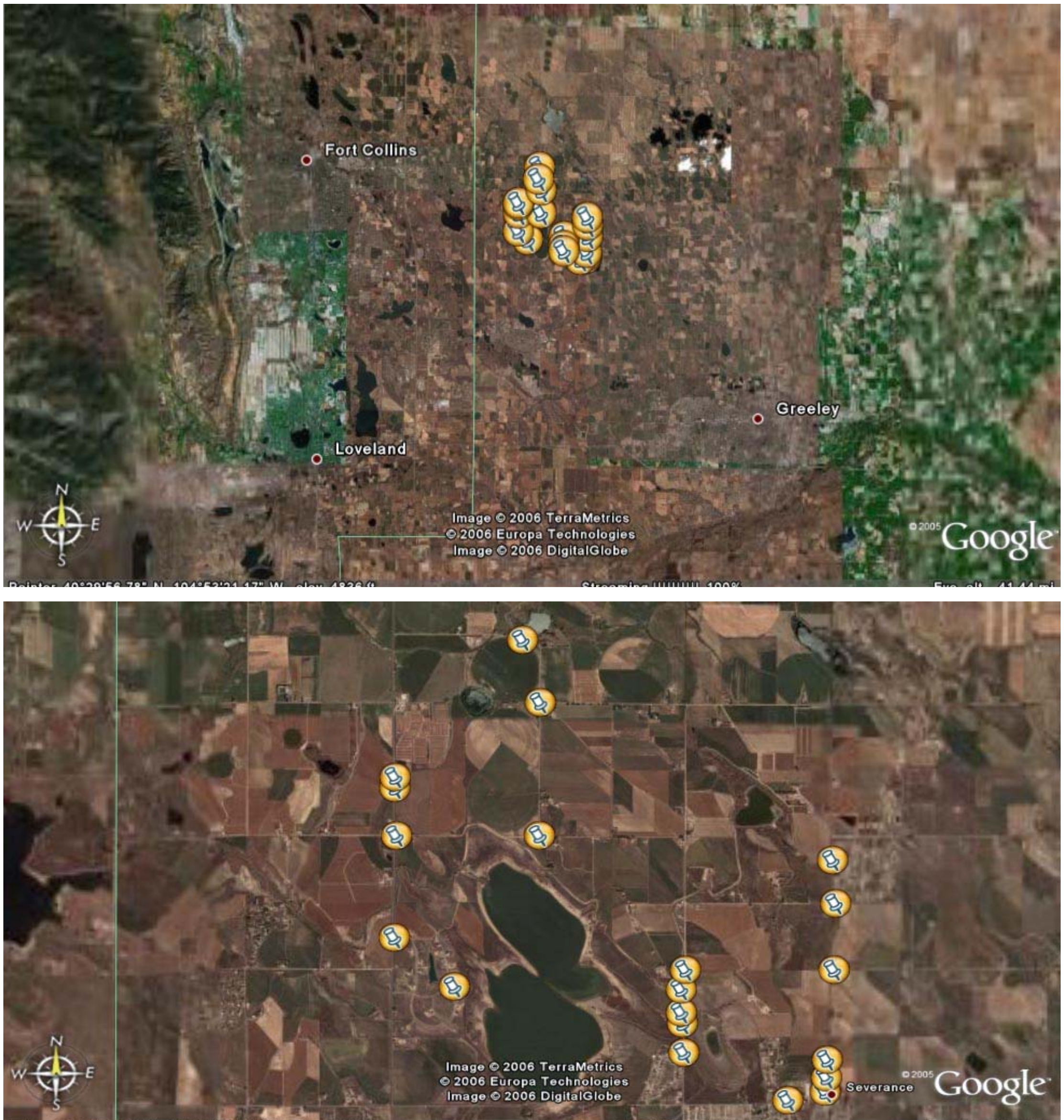


Figure 7: Ground verification of damage and hail sizes for the June 19th storm was conducted at the highlighted points. Pea size hail was the most often reported size and minimal damage was reported.

of the damage in that specific area. The area where the damage was reported can be seen in figure 7.

Also in this hailstorm, hail of 0.75 inches in diameter was reported by Storm Prediction Center spotters in Fort Collins Colorado and winds estimated at 80mph were reported in western Weld County.

According to Storm Prediction Center's storm reports, a tornado of an unknown F scale touched down at about 2327 UTC in Logan County on August 24, 2002. Also, reports of hail of 1.75 and 0.75 inches in diameter, and of trees were also reported down all over the county.

The first step required for this project was finding the best days to collect MODIS data. We found cloud-free days before and after the storm took place and analyzed the NDVI values for our areas of study. Cloud-free dates are important for the acquirement of data, since clouds would block the visible and near infrared information from the crops needed.

For the June 19th 2002 storm, we selected the day before the storm (June 18) as the "before" MODIS data and June 26 (seven days after the storm date) as the "after" MODIS data. When it came to the August 24th 2002 hailstorm, August 17th was used as the before date (seven days before the storm) and the after date was August 30th, (six days after the storm).

The objective in MODIS data gathering was to follow Erickson et al (2000) as closely as possible. That research found the most accurate time to acquire satellite data is 7-10 days after the storm hits. This was not followed exactly due to cloud cover in the area. After the data was acquired it was calibrated for this geographic area.

After the MODIS data was gathered, calibrated, and the NDVI was calculated, the NDVI was plotted as a function of distance from the radar. Then the researchers looked for any visual differences between the before and after images such as an area with smaller NDVI values, or a lesser amount of vegetation increase in the path of these thunderstorms. The NDVI plots for the two storms can be seen in figures 8 and 9. As you might see with both images, an overall increase in the NDVI is apparent. In figure 8, the NDVI did not show an apparent hailstreak. The June 19, 2002 hailstorm showed H_{DR} values that were much less predominant then the August 24 storm. This was considered to be a trial where we could look for the minimum threshold for the NDVI H_{DR} correlation.

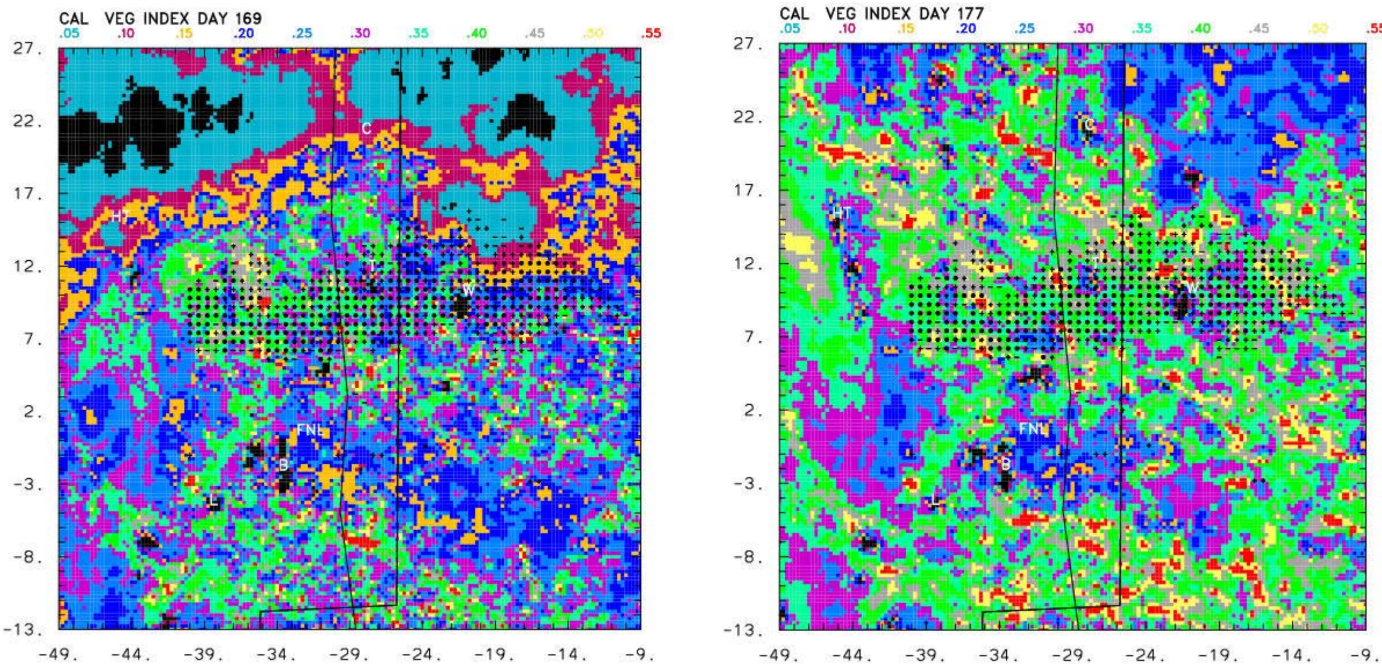


Figure 8: Left – The NDVI plot before the hailstorm hit the area (June 18, 2002)
Right – The NDVI plot after the hailstorm hit the area (June 26, 2002)
Both images include where the highest H_{DR} values were concentrated (dots, plus, minus). the axis represent distance from the CHILL radar.

On figure 9, the August 24, 2002 hailstorm which produced the largest H_{DR} values had an apparent hailswath that could be easily seen on H_{DR} data in Logan County near Sterling, Colorado. When the H_{DR} values were plotted over the NDVI values, it became apparent that the two coincided and the change in NDVI occurred in areas with high H_{DR} values.

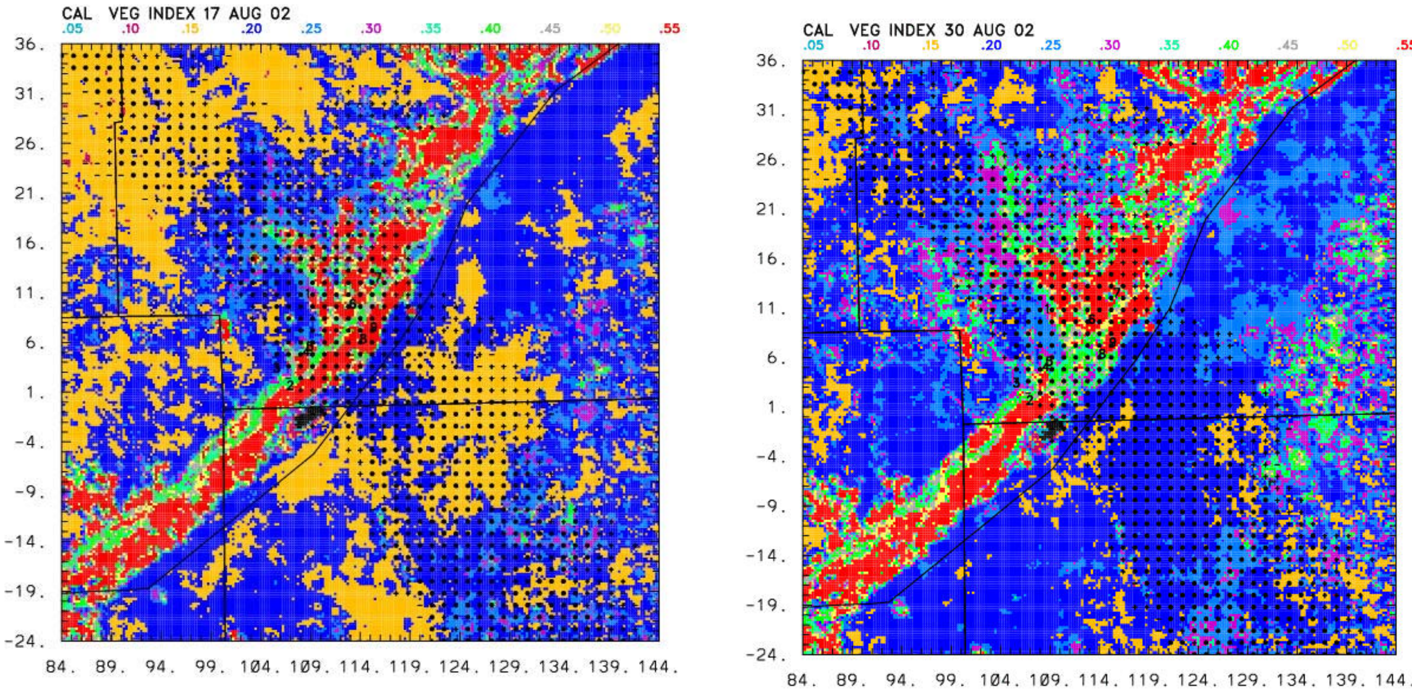


Figure 9: Left – The NDVI plot before the hailstorm hit the area (August 17, 2002)
Right – The NDVI plot after the hailstorm hit the area (August 30, 2002)
Both images include where the highest H_{DR} values were concentrated (dots, plus, minus). The axes represent distance from the CHILL radar.

These NDVI and H_{DR} values were then submitted to statistical analysis. Since these were in a text document and included a larger area then affected by the storm, areas with H_{DR}=0 were neglected since most likely nothing happened in that area. Also, areas with low NDVI values (less then 0.2) for the “before” day were not included since this could have been bare soil, pasture land, lakes, or vegetation that would possibly not be damaged by hail.

For the June 19th 2002 storm, an overall average of all H_{DR} points reveal a medium of 3.23 and an average of the change in NDVI reveals a medium value of 0.065, versus 0.36 for areas that received rain (negative H_{DR} values).

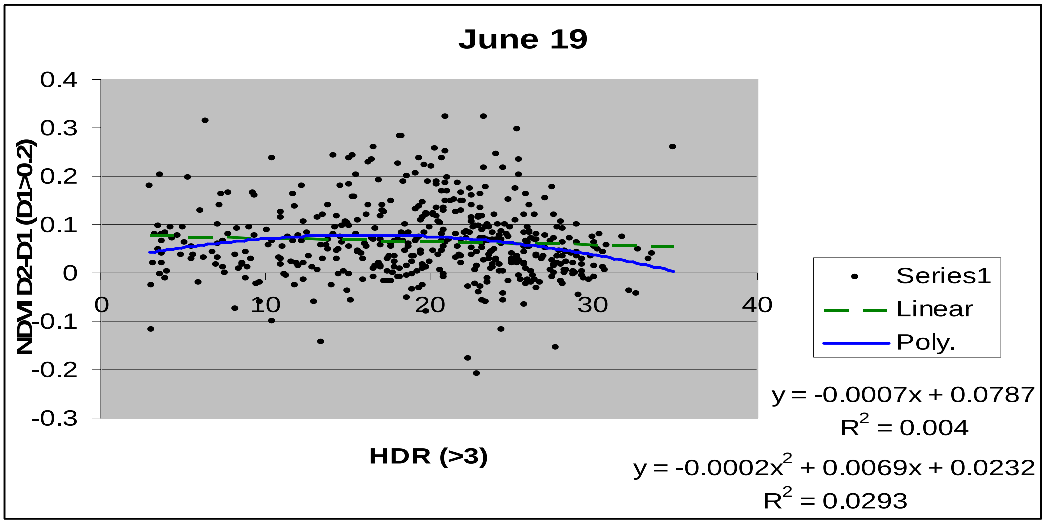


Figure 10: A scatter plot of the June 19th hailstorm showing the H_{DR} values over the NDVI difference. A linear best fit line, as well as a polygon best fit line, was added to show the decreasing trend in the data.

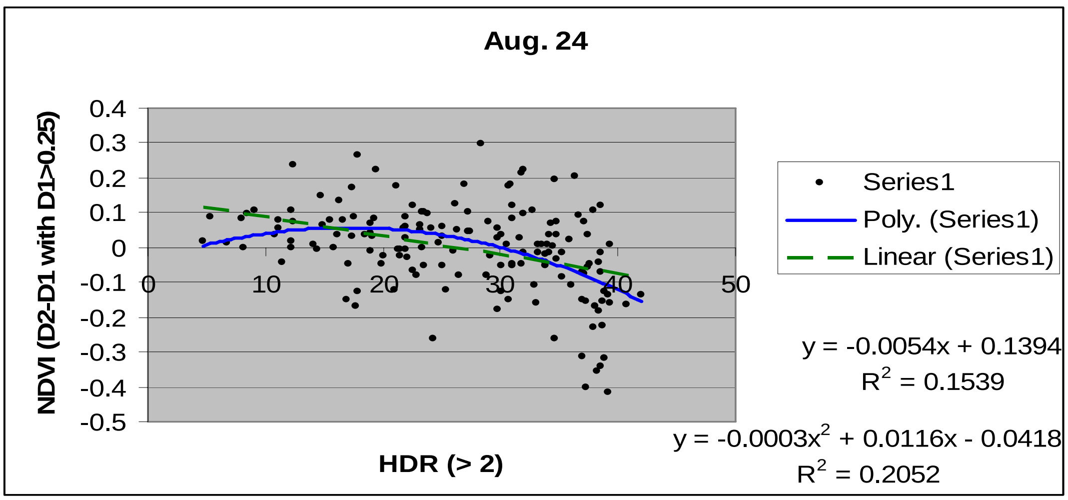


Figure 11: **A scatter plot of the August 24th hailstorm showing the H_{DR} values over the NDVI difference. A linear best fit line, as well as a polygon best fit line, was added to show the decreasing trend in the data.**

For the August 24, 2002 storm, an overall average of all H_{DR} points reveal a medium of 22.63 and an average of the change in NDVI reveals a medium value of -0.004414.

Both storms showed a downward trend at HDR ~ 30. This was noticeably illustrated by the August 24th plot (figure 11)

Conclusion

Hailstorm damage to crops cause millions of dollars in damage every year and it is a major concern to farmers in northern Colorado. The purpose of this REU project is to determine if there is a correlation between H_{DR} data from the polarimetric CSU-CHILL radar data as well as and NDVI data from the MODIS in the Terra satellite.

Analysis of the NDVI showed that spectral variances can be seen between the undamaged and damaged vegetation for the August hailstorm. This is compatible with the fact that plants' ability to conduct photosynthesis will be unconstructively changed due to hail damage. The amount of leaf damage, the stage of the plants life, and the overall health of the plant are closely matched with the crop's ability to recover from hail damage (Koll, pers. comm.). The crop's molecular structure changes with hail damage thus changing the near infrared photosynthesis signature shown in the NDVI.

Since the damage that was done to the June crop was of a smaller magnitude, and the corn was a premature crop standing no more then four feet in height, the corn was expected to recover from the hail damage. Farmers also expected the crop would to survive the hail damage and continued to water the corn. Since most leaves did not fall to the ground and die, the NDVI should not have shown much damage (or any damage at all) after the storm passed. An example of the hail damage to the young crop can be seen on figure 12.

Figure 12: June 19, 2002 damaged young corn that could recuperate before the harvest.

Limitations

Several limitations need to be addressed in future studies of this nature. The first is that, due to time limitations, only two hailstorms were studied in this project. As a guideline, two storms are never representative of the climatology of our area, so more hailstorms should be chosen and studied. It was not possible to choose a hailstorm that happened this year since none were available.

Secondly, only the August storm was strong enough to exhibit a NDVI change great enough to be clearly seen through statistical analysis. The R^2 calculations showed a very low correlation between the data points and the line of best fit for both storms (see figures 10 and 11). This is to be expected when using MODIS data (Kiddler, pres. comm.) since not every point behave the same and slight variability in the crop could influence these numbers. This project could be used as a guideline for future researchers to selecting hailstorms in northern Colorado.

Finally, vegetation greatly varies within a few miles in Colorado. The NDVI values for crops such as corn, wheat, sugar beats, as well as other commonly grown crops changes with each plant. Conducting this analysis in hailstorms in an area with uniform vegetation might yield a better tool for storm analysis.

All of the factors mentioned above keep this tool from being used as a main source for information about crop damage in Colorado. This could be used as explained by Apan et al. as a guide of where the major damage occurred instead of a main tool.

Future Research

An additional study will be conducted over the next two months where researchers will look at a severe hail storm in Oklahoma that occurred on May 29th, 2004. Data was gathered from the National Severe Storms Laboratory's polarimetric radar (KOUN) and from MODIS. May 28th, 2004 MODIS data was selected for before the hail event and June 11th, 2004 was selected for comparison. An analyses of the data gathered for this storm will be presented during the meeting.

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