4B.2 An Analysis and Evaluation of the Agreement between Severe Geostationary Satellite and National Weather Service (NWS) Radar Signatures during the Fall of 2008

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ABSTRACT

This paper provides analysis and evaluation of severe weather signatures of the Geostationary Operational Environmental Satellite (GOES) and NWS radar graphical products publicly available on the internet. The severe events examined are from September through November of 2008. These events were randomly chosen to illustrate the comparison and agreement between signatures of GOES satellite and NWS radar products. Discussions of these events and the associated satellite and radar products include illustrated examples and specific graphical highlights of what constitutes a severe weather signature.

The GOES severe weather signatures emphasized in this paper include visible satellite overshooting tops and enhanced-V infrared (IR) satellite signatures. Severe weather signatures identified using NWS radar include high-reflectivity returns, bow echoes, hook echoes, and Doppler velocity signatures. Many of these signatures are easily identifiable from publicly available graphics on the internet at National Atmospheric and Oceanographic Administration (NOAA) and NWS sites. Websites for the products are provided in the paper's reference section.

A primary goal of this paper is an evaluation of a particular severe weather event and the determination of the agreement between identification of severe signatures, as determined by NWS radar and those depicted by GOES satellite data, via visual examination or derived data products. This paper will present a qualitative comparison of severe weather events depicted on both GOES satellite data and NWS radar signatures. Primary evaluation methodology is a graphical comparison between the location of severe signatures on both the satellite and radar images. Spatial extent, specific characteristics, and temporal duration are also facets of the evaluation used in this study.

An additional goal of this paper is to emphasize the public availability of products showing locations where severe weather has a high potential of occurrence or where it is already in progress. A direct impact of the accessibility to, and familiarity with, these products is they may increase awareness of severe weather threats. A person or family with internet access in their home can view these products during periods when severe weather is nearby and have a general awareness of where severe weather is occurring. These products, combined with information available from television or radio broadcasts, may enable the public to develop a better understanding of imminently developing severe weather. Ultimately this may result in lives saved.

I. Introduction

A fundamental part of the mission of the National Oceanographic and Atmospheric Administration (NOAA) and the National Weather Service (NWS) is to provide environmental event information for public use [1]. Providing information for severe weather events is a critical component of the NOAA mission. This paper provides an analysis and evaluation of a subset of the products NOAA and the NWS distribute via the Aviation Digital Data Service (ADDS) [2]. The subset of products were gathered during severe weather events occurring from September through November of 2008 and includes Geostationary Operational Environmental Satellite (GOES), Next Generation weather Radar (NEXRAD), and ADDS winds and temperature analysis charts. These products and other NOAA products are readily available to the public to use for advance planning and real-time awareness of severe weather events. This paper examines two fundamental aspects of these severe weather products: 1) the agreement in time and location of severe weather signatures between GOES and NEXRAD products and 2) whether the products provide information the public can use to identify severe events as well as whether the public can locate the severe event, relative to their location. The examination includes a discussion on the availability of these products to the public and the methods used to interpret the products for identifying severe weather signatures. Use of these products for public awareness of severe weather threats and for actions necessary to save lives is included in the discussion.

II. Analysis Data

Analysis data products for this paper include GOES and NEXRAD products from the ADDS website. The visible and color-enhanced infrared (IR) GOES imagery from the site were used to identify likely areas of severe weather. Figures 1a and 1b provide an example of the GOES imagery for a severe event over eastern Florida on 30 November 2008 at 1855Z. Figure 1a shows the 1km visible image and Figure 1b shows the 4km color-enhanced IR image. The red circle indicates the location of the severe weather event on both figures.

The corresponding NEXRAD radar images for the same time are provided in Figures 2a and 2b. The image in Figure 2a is the composite reflectivity from the Melbourne, FL (MLB) radar at 1855Z on 20 November 2008, and the image in Figure 2b is the

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storm relative velocity image for the same time and date.

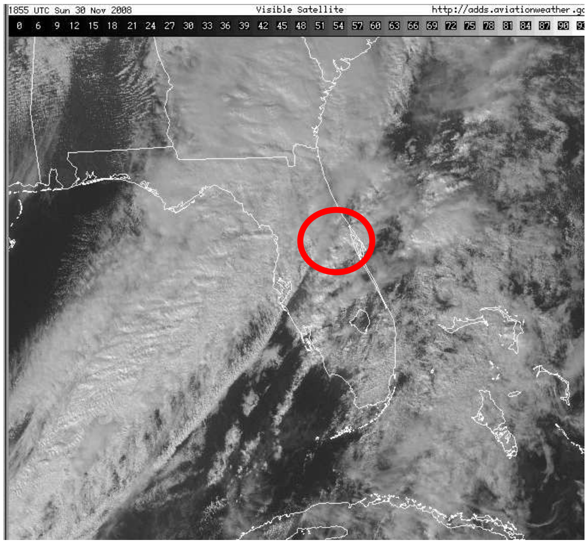


Figure 1a. GOES CONUS Southeast sector 1km visible image at 1855Z on 30 November 2008.

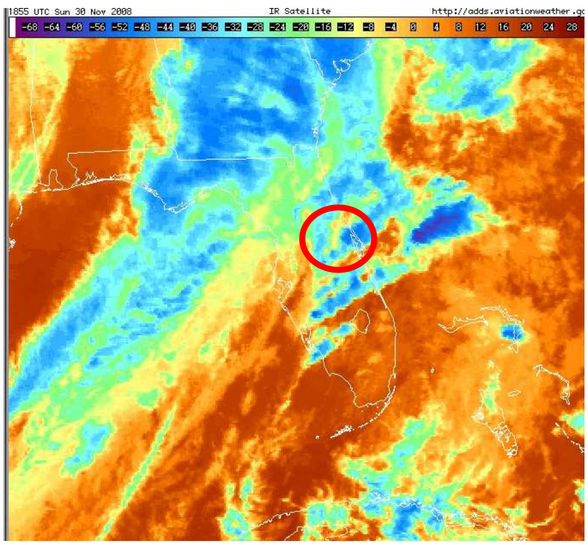


Figure 1b. GOES CONUS Southeast sector 4km color-enhanced IR image at 1855Z on 30 November 2008.

Using the GOES imagery, the identification and analyses of severe events include the following basic techniques: 1) over-shooting tops and any associated shadowing for the visible imagery; and 2) enhanced-V signatures based on the cloud-top temperature color table for the color-enhanced IR imagery. The severe event identification using the NEXRAD imagery included the following basic radar techniques: 1) bow and hook echo signatures for the composite reflectivity images; and 2) the Doppler velocity mesocyclone signature method for the storm relative velocity images.

Detailed information on the enhancement curve used for GOES IR color-enhanced imagery on the ADDS website was not available. Color scales relate colors to temperature values in the imagery, for both gray scale and color enhanced images and are shown with all imagery included in this paper.

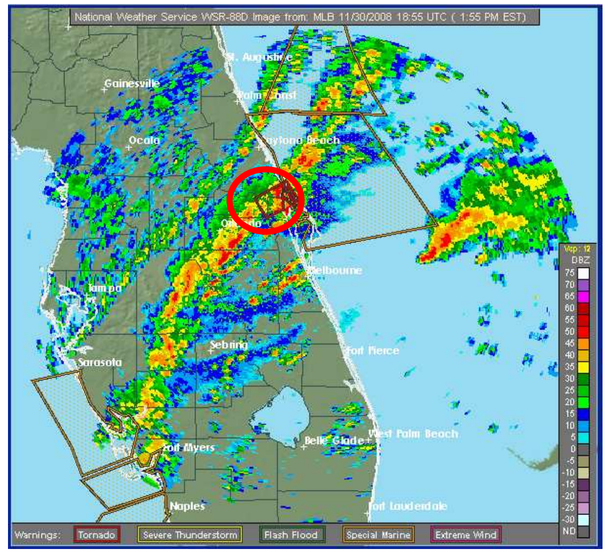


Figure 2a. NEXRAD composite reflectivity image from MLB at 1855Z on 30 November 2008.

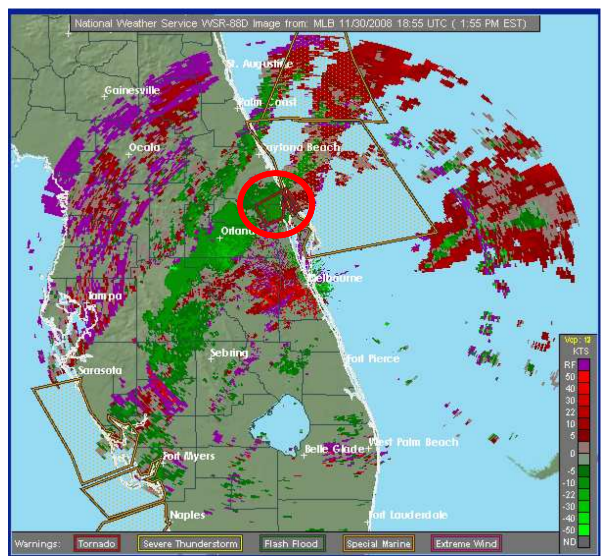


Figure 2b. NEXRAD storm relative velocity image from MLB at 1855Z on 30 November 2008.

In all cases the accuracy of locating severe weather events depends on the imagery resolution. As with all geographically located data products, the accuracy of delineating areas affected by the severe weather events is directly related to the spatial resolution of the data used to create the graphical imagery. For the GOES satellite images, the visible imagery (grayscale images) resolution is 1 km and the IR imagery (color enhanced images) resolution is 4 km. [3]. The 1km or 4 km pixel resolution satellite products could lead users to incorrectly locate severe weather events, without supplementation of finer resolution data sets such as NEXRAD.

The NEXRAD reflectivity mode short range grid, used during severe weather event detections, is 1.1 nm. The composite reflectivity range is 143 miles. Base reflectivity returns are measured on a .5 nm grid while precipitation returns are measured on a 1.1 nm grid. Doppler velocity is measured at 250 m by 1 degree over a 230 km range [4].

These data were gathered for 6 severe weather events. Of those 6 events, 5 led to severe wind reports, 4 led to severe hail reports, and 3 led to tornadic reports [5]. Out of those 6 events, the data products for **Event 1** (5 September 2008) and **Event 2** (30 November 2008) were selected to be included in this manuscript. These events were chosen because they provide the best representation of the severe signature techniques emphasized in this paper. A detailed discussion for the data products from these two events is in the next section and in some cases include supplemental data emphasizing the specific severe meteorological situation.

III. Severe Event Analyses and Data Examination

Event 1. The first event analyzed and examined occurred on 5 September 2008 over western Kansas. Figures 3 through 6 provide an initial look at the visible and color-enhanced IR GOES imagery for this event. Figure 3 shows the 1km visible imagery over the severe area.

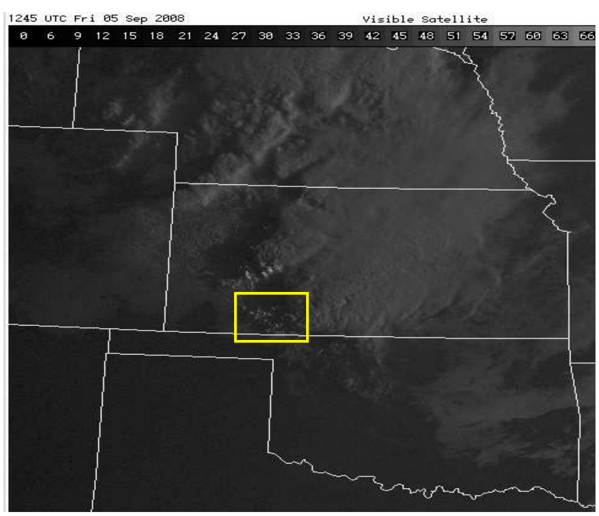


Figure 3. Visible GOES imagery at 1245Z on 5 September 2008 over Kansas.

The noteworthy features on this image are the sun-illuminated convective towers at the southern end of the convective system. Time of day plays a significant role in portraying the ideal sun-earth geometry for this type of illumination. In this case, the imagery is from 1245Z on 5 September and the sun is at a low elevation angle to the east. This best illuminates the eastern sides of the convective towers. However, as the NEXRAD data shows, the area in the yellow box had the highest reflectivities and thus the most severe potential.

Figure 4 shows the rapid development of the two more distinct towers, indicating an area of strong updrafts characteristic of a developing severe system. From 1245Z to 1255Z the convective towers grew in areal extent and separated into two distinct cells. A radar coded message graphic from another ADDS link showed the highest tops, above 40,000 feet at both times, were also inside the yellow boxes in Figures 3 and 4. Tops of this height, at this time of day, are another indicator of a strong convective system.

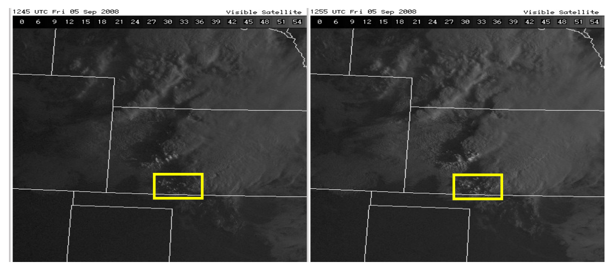


Figure 4. Time-phased GOES visible images for 1245Z and 1255Z on 5 September 2008 with illuminated convective towers over western Kansas.

Figures 5 and 6 provide the same information as Figures 3 and 4 using the ADDS color-enhanced IR images. Figure 5 is a close up view of the color-enhanced IR image for 1245Z on 5 September 2008. A comparison with Figure 3 shows the difference in the resolution between the visible and IR images, and also shows how the two images depict the severe convective tower area.

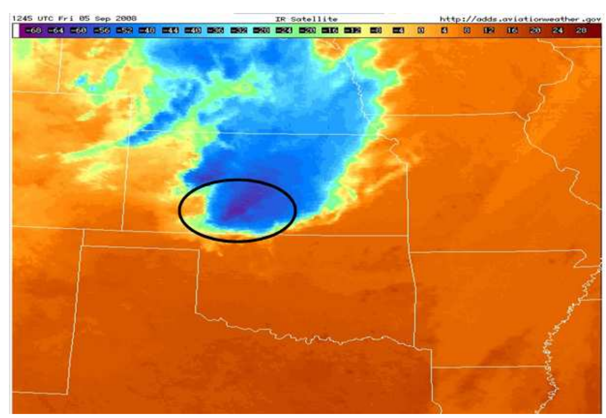


Figure 5. Color-enhanced IR imagery at 1245Z on 5 September 2008 over Kansas.

Figure 6 provides the time-phased color-enhanced IR images for 1245Z and 1255Z over the south central Kansas area. These color-enhanced images also show the area develops and moves southeast over this time period. These images also show the tops developed to a vertical height corresponding to cloud-top temperatures of -60°C (indigo) and a corresponding height of 40,000 ft based on the 1200Z, 5 September 2008, Dodge City, KS Skew-T plot [6]. This image also provides a view of the low (yellow and tan) and middle (green) cloud associated with this convective storm system.

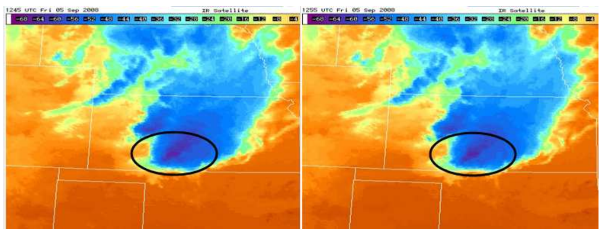


Figure 6. Time-phased GOES color-enhanced IR images for 1245Z and 1255Z on 5 September 2008 over western Kansas.

Figures 7 and 8 show the NEXRAD images for Wichita, KS for the same time periods as the GOES imagery. Figure 7 is a single frame with the composite reflectivity from Wichita at 1245Z on 5 September 2008. There are several pixels in this image with reflectivity returns of at least 65 DBz. These pixels are highlighted with the white Xs. A quick comparison with the GOES imagery shows the high reflectivities correspond to the developing convective towers shown in the highlighted yellow boxes on Figure 4. Based on this analysis the NEXRAD radar for Dodge City, KS would have better shown the reflectivity returns from the two bright convective towers in Figure 3, but Wichita was selected for this paper.

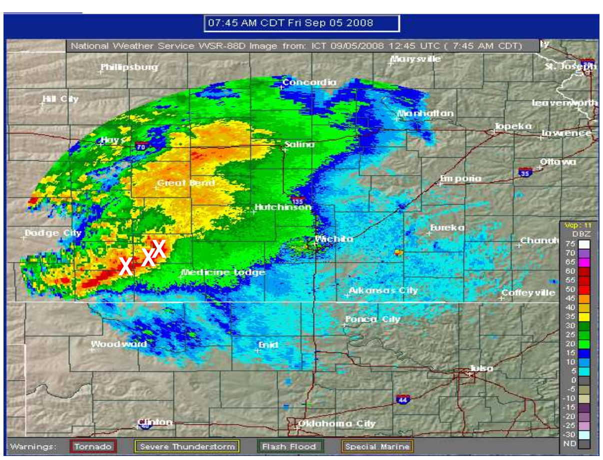


Figure 7. Wichita, KS NEXRAD composite reflectivity image for 1245Z on 5 September 2008.

The time-phased images in Figure 8 show the movement of the potentially severe area to the east southeast toward Medicine Lodge, KS. The left image is at 1245Z and the right image is at 1255Z. Note that by 1255Z, the 65DBz reflectivity returns are no longer present in the radar image. Storm relative velocity imagery was not collected for this event.

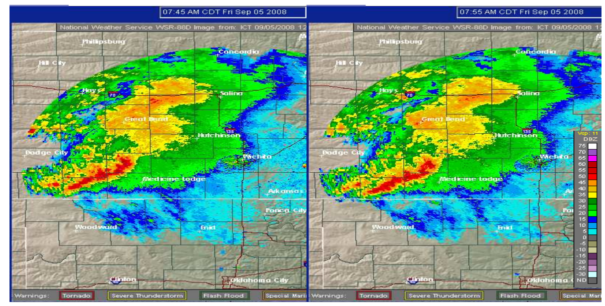


Figure 8. Time-phased NEXRAD images from Wichita, KS at 1245Z and 1255Z on 5 September 2008.

Figure 9 provides a comparison of the visible satellite imagery and the NEXRAD composite reflectivity at 1310Z on 5 September. Note that the convective area on the border of Kansas and Oklahoma is producing reflectivity returns of at least 65 DBz. In this area, there is good agreement between the visible satellite where convective towers are rapidly developming, and the high reflectivity returns on the border. For this event GOES visible satellite and NEXRAD composite reflectivity provide a good general location of the developing severe conditions. However, it is the author's opinion that the NEXRAD composite reflectivity images provide the general public with a better charaterization of severe potential. High reflectivities colored in red are more easily interpreted as a dangerous condition than the visible satellite imagery. Also, satellite interpretation requires knowledge of how to distinguish bright, sunlit convective towers from other bright sunlit features. Even the color-enhanced IR GOES imagery requires training on interpreting convective features versus other high cloud features, with dark blue colors based on the cloud pixel temperatures. The advantages and disadvantages of NEXRAD storm relative velocity images are discussed as part of the Event 2 discussion.

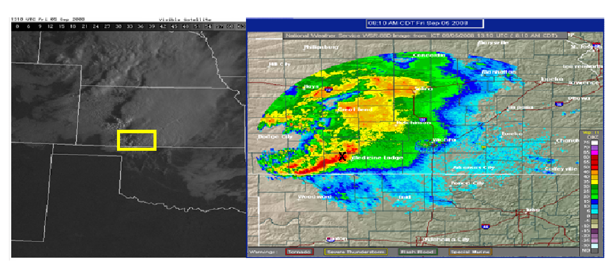


Figure 9. GOES visible and NEXRAD composite reflectivity images for 1310Z on 5 September 2008. The NEXRAD image is from Wichita, KS.

Event 2. The second event occurred over eastern Florida on 30 November 2008 around 19Z. This event resulted in multiple severe events in central, eastern, and southern Florida. These severe events included several tornado warnings. The data for this event included the same imagery as the 5 September 2008 event with the addition of the NEXRAD storm relative velocity imagery. Figure 10 provides a time-phased comparison of the GOES visible imagery at 1845Z and 1902Z on 30 November.

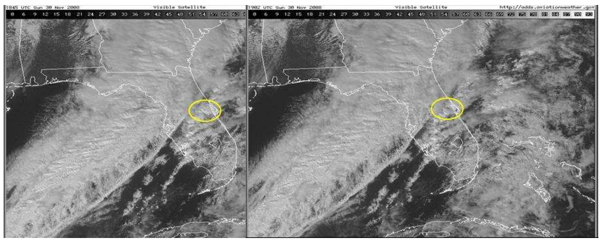


Figure 10. GOES visible imagery at 1845Z and 1902Z on 30 November 2008.

The visible imagery in Figure 10 shows how quickly the convective area inside the yellow ellipse develops in a 17-minute period. At 1845Z the convective towers are just beginning to penetrate the cirrus anvil top of the convective cell. By 1902Z, the towers are well above the anvil and are high enough to cast shadows on the eastern side of the cirrus anvil. These "over-shooting tops" are indicative of severe potential in and around that cell. The severe condition could be hail, wind, flooding rain, or tornadic activity. Figure 11 provides the corresponding Melbourne, FL NEXRAD composite reflectivity images for this same area and general time period.

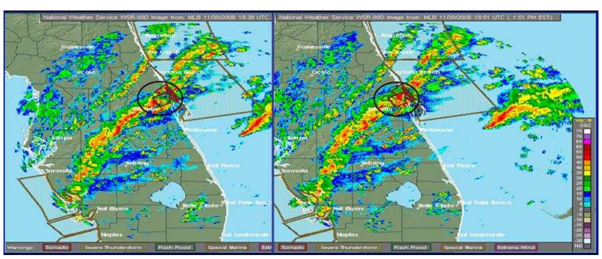


Figure 11. Melbourne, FL NEXRAD composite reflectivity images at 1838Z and 1851Z on 30 November 2008.

The area inside the black ellipses in Figure 11 show a severe and tornadic area developing to the west of the Cape Canaveral, FL area. An area of composite reflectivity with red pixels on the image is present at 1838Z. This area also corresponds to two red-outlined polygons indicating tornado warning areas north and west of the Cape. By 1951Z, the red pixel area on the map is inside the southern warning polygon. Note that the northern warning polygon was displayed at 1821Z, or earlier. Also, note these image times indicate the time imagery was captured at the satellite; there is a lag time to upload images to the web site. There may be more timely information available from the NWS via other means. For the same reasons discussed as part of the Event 1 analysis, the general public viewing these images over the internet NWS site is better able to understand that the red pixel areas are more easily associated with severe weather potential than information discerned from visible satellite imagery.

Figure 12 shows the developing severe area using the GOES color-enhanced IR imagery time-phased from 1845Z to 1902Z. The 1845Z image depicts a distinct dark blue pixel value area indicating convective vertical development to a height corresponding to an upper level in the atmosphere with a temperature between -56°C and -60°C. The 1902Z image indicates a less intense area and thus the lighter blue pixels, or lesser vertical development and lower cloud tops. However a closer examination and comparison between the visible and the color-enhanced IR imagery indicates the lighter blue shading may be due to other thin cloud surrounding or obscurring the cloud tops. The result may be the temperature, or light-blue shading, is a combination of two cloud layers causing conflicting information collected by the GOES satellite. As was discussed earlier, the IR imagery also has a lower resolution than the visible satellite imagery. Due to these types of interpretation errors, the GOES color-enhanced IR imagery may not provide a good source of severe weather awareness for the general public.

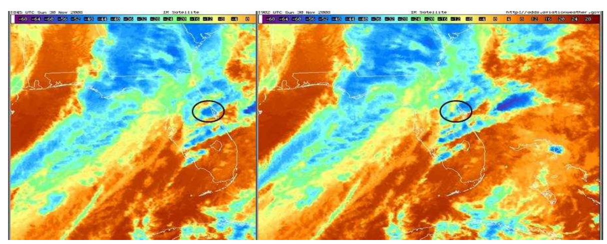


Figure 12. Color enhanced IR GOES imagery at 1845Z and 1902Z on 30 November 2008 over Florida.

This event also includes the NEXRAD storm relative velocity imagery as part of the analysis. Figure 13 provides the NEXRAD storm relative velocity images time-phased from 1851Z to 1900Z on 30 November. These times were chosen to show the storm relative velocity tornadic vortex signature provided by the NEXRAD Doppler scan.

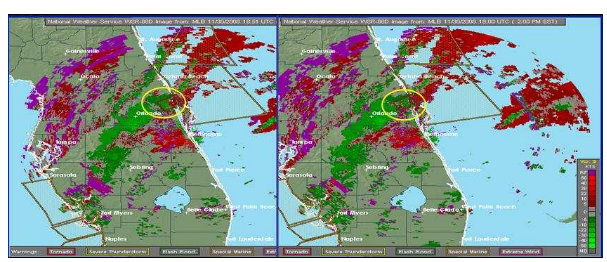


Figure 13. Melbourne, FL NEXRAD storm relative velocity images at 1851Z and 1900Z on 30 November 2008.

A close look at Figure 13 shows the 1851Z image has the distinct tornadic velocity signature indicated by the opposite red and green velocity returns. As is well documented in doppler radar meteorology, these opposite velocities indicate a rotational area and likely mesocyclone associated with a tornado or an area with high tornadic potential. Note that the tornadic signature occurs inside the red tornado warning polygon. Although interpreting and identifying this storm relative velocity signature is an expected capability for most meteorologists, the general public may not have the skills to make the required associations to locate areas with tornadic potential.

Figures 14 and 15 provide a comparison of 3 different data types. Figure 14 shows the GOES color-enhanced IR imagery and the NEXRAD storm relative velocity imagery. Figure 15 shows the GOES visible imagery for the same time, 1955Z, as the color-enhanced IR imagery while the NEXRAD imagery is at 1952Z. Each of these images provides an indication of a potentially severe wind event.

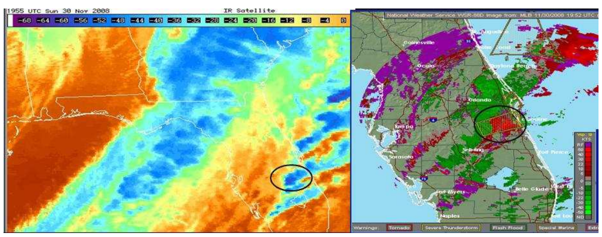


Figure 14. Color-enhanced IR GOES image and NEXRAD storm relative velocity images over Florida showing high wind warning area around 20Z on 30 November 2008. The IR image is shown at 1955Z and the NEXRAD image is at 1952Z.

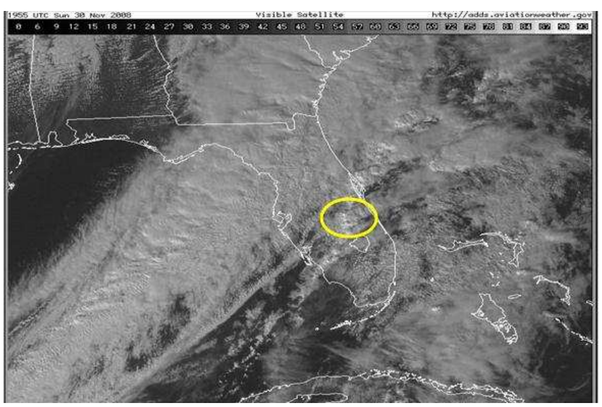


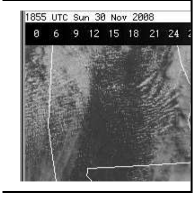
Figure 15. GOES visible imagery at 1955Z on 30 November 2008. Area within yellow ellipse shows developing convective towers associated with the wind warning area highlighted on the NEXRAD storm relative velocity imagery in Figure 14.

For **Event 2**, the tornado warning and high wind severe events discussed in the analysis, the NEXRAD storm relative velocity imagery provides the best graphical signatures of location and intensity. The composite reflectivity indicates the areas of strong reflectivity and associated heavy rain with the intense convective cells, but does not directly provide data indicating the severe winds and mesocyclone with tornadic potential. Perhaps if the imagery graphically displayed on the NWS website were interactive to allow a zooming capability, a “hook echo” reflectivity signature from the composite reflectivity could be detected. However, with the current site functionality, only the implied high winds or severe potential are possibly seen, based on the intense red reflectivity returns. As stated for **Event 1**, the authors believe the composite reflectivities are most easily interpreted by the general public user community. As a result, for the **Event 2** severe situation the public should have enough information to determine severe potential at a specific location based on the NEXRAD resolution and the associated map.

Our analysis of the GOES satellite imagery for **Event 2** shows that a user with general meteorological satellite interpretation skills can identify specific storm structure features based on the visible and color-enhanced IR GOES imagery to infer areas with severe potential. However, the authors don’t believe a general public user could associate the visible and IR satellite features with severe storm structures, and understand the differences in the resolution or the technical basis of color-enhanced imagery as it relates to severe weather. So, the general conclusion, as was determined for **Event 1**, is that composite radar reflectivity imagery still provides the better information that satellite imagery to the general public to identify areas of severe potential.

IV. Conclusions

The analysis and examination completed in this paper demonstrate NOAA and the NWS provide an excellent collection of products for evaluating the potential for severe weather. These products are easily accessed and are available to the general public. For this paper the products on the ADDS and NWS NEXRAD internet sites were used to examine severe weather events. Although the ADDS site is primarily intended for general aviation guidance, the site has an excellent collection of satellite and graphical products to use to identify weather events including those with severe characteristics and potential. The NWS NEXRAD site also provides an excellent collection of reflectivity and storm velocity products. A key objective of this paper was to determine whether severe weather information in graphical form was easily accessible by the general public. Each of these sites satisfies this key objective. A related goal with this objective is to increase public awareness of severe events impacting daily activities and safety. With some public education and outreach, this goal is easily achievable.



The primary goal of this paper, to be able to use weather data and products to identify locations of severe weather, was also satisfied. GOES and NEXRAD products for 6 severe events were analyzed and 2 events, 5 September and 30 November 2008, are included in this paper. The other events were 1 September (Hurricane GUSTAV landfall), 2 September (post landfall), 30 September, and 11 November 2008. The analysis of the 2 specific events, 5 September and 30 November, included detailed discussions of four data types: GOES visible, GOES color-enhanced IR, NEXRAD composite reflectivity, and NEXRAD storm relative velocity. Using these products, specific severe weather signatures including an intense convective cell producing severe hail conditions (5 September), and a convective system producing a mesocyclone storm relative velocity signature with tornadic potential were identified.

An additional goal of determining whether the general public is capable of interpreting the imagery products and identifying severe weather locations was also addressed. In the opinions of these authors only the NEXRAD composite reflectivity imagery provides the public with interpretable information that the severe weather potential exists. The high reflectivities are easily associated with very heavy rain and strong convective systems. Our belief is the general public does not have the required training to consider the satellite and doppler radar meteorological principles to identify GOES or NEXRAD severe signatures. In almost all cases the public requires the additional information available from television, radio, and direct NWS broadcast to be alerted of the severe weather potential and time of occurrence relative to their location. One additional comment is that adding a capability on both the ADDS and NEXRAD sites of an interactive zoom function would help both the public and the meteorological community with the interpretation and locational orientation of severe weather signatures.

Future enhancements to NEXRAD computer processing and signal processing will increase the spatial resolution of radar returns and improve severe weather event detection. The addition of dual polarization transmission will provide the capability to depict atmospheric structures in three-dimensions. These two advances will yield benefits to the meteorological community as well as general users.

Additional enhancements to user utility could be made by providing direct data download access to both radar imagery and satellite imagery on the ADDS and NWS sites. Currently the only way to download these images is via screen capture. If these image files would be available for direct download into GPS systems, it would greatly enhance the value to the public at large. User interactivity, whether enabled online or via user GPS or other local display capabilities, would provide huge steps toward increased utility. This interactivity would include zoom capability, the ability to add user defined overlays (buildings, geographic features, transportation networks, etc). These features are key to providing 21st century capabilities to the user community at large and will pay off in property and life protection.

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