Analysis of STS-134 Hail Event at Pad 39A, March 30, 2011

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SUMMARY

During the late afternoon of March 30, 2011 at approximately 21:25 - 21:30 GMT, hail monitor stations at Pad 39A recorded rice to pea size hail. The duration of the event was approximately 5 minutes. The maximum size detected by the three hail monitors was 10 – 12 mm. The 12 mm marble size value was measured by the active impact sensor at site #2, which experienced high winds. This 12 mm measurement may be artificially higher by one or two mm due to the extra hail kinetic energy resulting from the extreme horizontal winds. High winds from the west produced a few notable long streak-like dents in the hail pads. High winds were also responsible for damage to facilities near hail monitor site #2 on the west side of pad A (a dumpster was overturned, and a picnic table roof was demolished). NWS radar volume scan (see Figure 1) showed 60-65 dBZ reflectivity values in the lowest 4 scan elevations around and over the pad 39A area. Since the lowest 0.5 degree scan showed a definite 65 dBZ signature, it is unlikely that hail had an opportunity to melt before reaching the ground. Some of the larger passive hail pad dents were shallower than what would be expected from solid frozen ice hydrometeor dents. Therefore, it is possible that the larger pea size hail may have been softer than the smaller rice size hail. This would be consistent with some melting before reaching the ground.

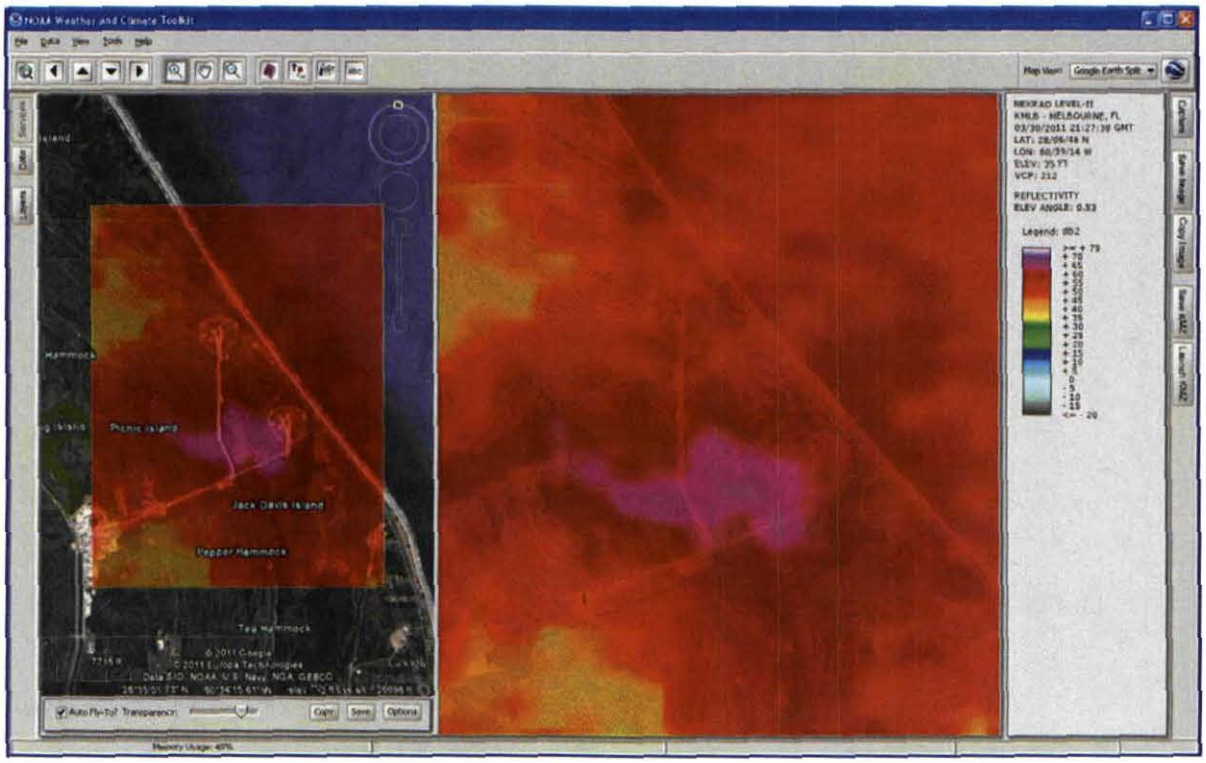

Figure 1. Melbourne NEXRAD reflectivity image for 03-30-2011, 21:27:38 GMT. Violet shading represents a reflectivity value of 65 dBZ, which is a good indicator of small hail.

BACKGROUND

Each hail monitor system consists of two independent measurements of hail size and count.

1. A *passive* hail pad (12 in sq Styrofoam covered with aluminum foil). For information on the passive hail pads, see: http://www.srh.weather.gov/mlb/cocorahs.html.
2. A 12 in sq *active* electronic sensor with DSP processing and LCD displays for counts per size channel. For theory of operation of the active hail monitor sensor, see: http://scitation.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=JASMAN000119 00000300EL47000001&idtype=cvips&prog=normal .

The small detection limit of the passive hail pad is approximately 4 mm. The low end detection limit of the active sensor is 8-9 mm. Ice pellets smaller than the low end size cutoffs may be detected in both cases, but the reliability of detection is greatly degraded. When hail is pea size (about 8 mm) or smaller, the active sensor may not sense it. However the hail pads will reliably measure the impacts for hail down to a 4 mm limit.

A hail pad calibration method relates the dent diameter d to the hail diameter D, as an empirical second order polynomial:

$$D = a_0 + a_1 d + a_2 d^2 \quad [\text{cm}] \quad , \tag{1}$$

where $a_0 = 0.38\,[\text{cm}]$, $a_1 = 1.11$, and $a_2 = -0.04\,[\text{cm}^{-1}]$. Equation (1) is plotted in Figure 2.

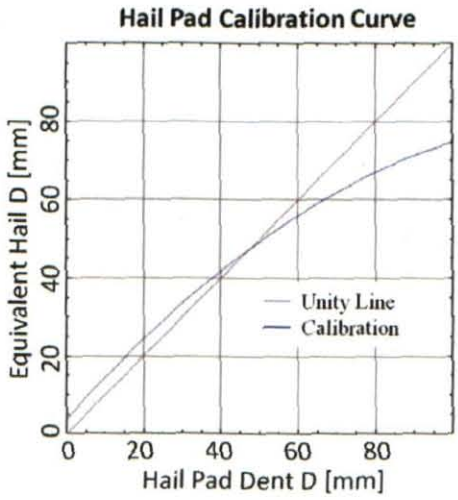

Figure 2. Hail pad calibration curve relating dent size to hail size.

The hail monitor system was first deployed to Pad-B in September 2006 for STS-115 support, several years after the STS-96 event. Two previous shuttles were damaged by hail, STS-117 on February 26, 2007, and STS-96 in May 1999. Detailed hail monitor data was collected and analyzed for the STS-117 event, http://ams.confex.com/ams/pdfpapers/129668.pdf (paper) and http://ams.confex.com/ams/presview.cgi?username=129668&password=129668&uploadid=8650 (poster). Figure 3 is a Melbourne reflectivity image of the STS-117 event which required a roll back to the VAB and extensive ET repair. However, it can be immediately seen that the

intensity of the STS-117 event was far greater than the STS-134 event of March 30, 2011 when comparing Figures 1 and 3.

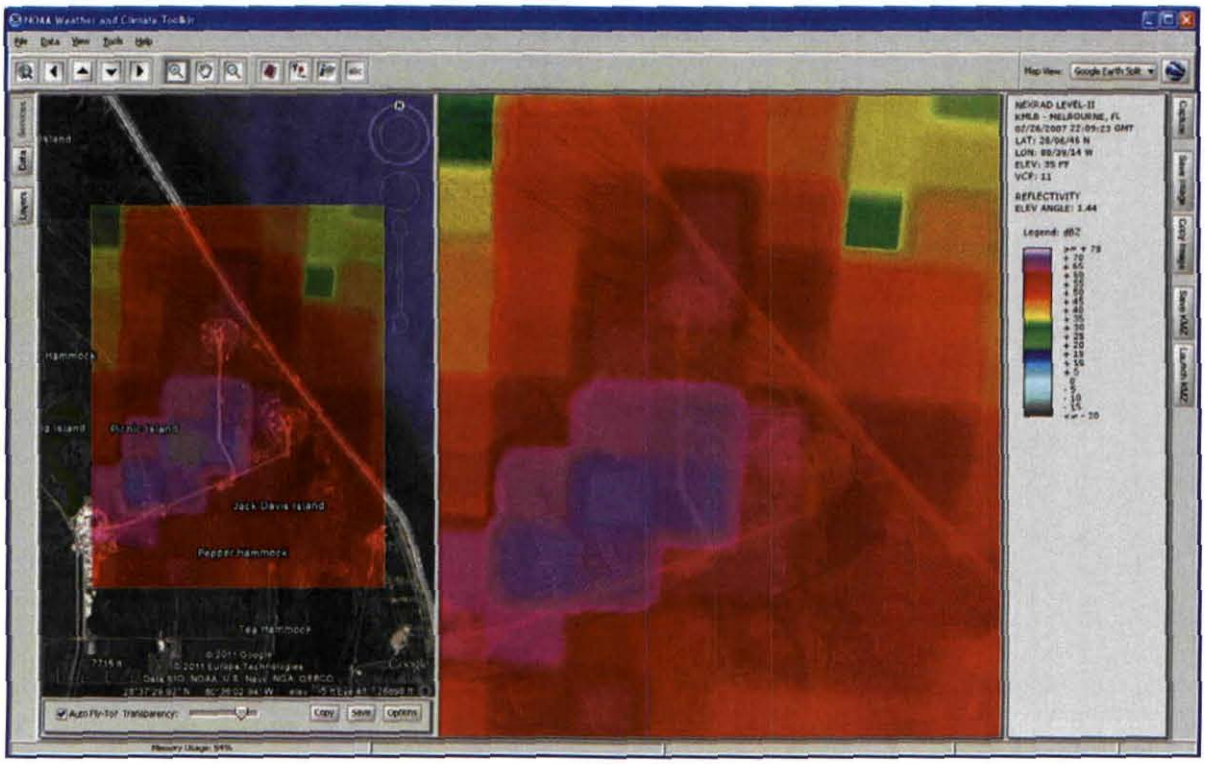

Figure 3. Melbourne NEXRAD reflectivity image for 02-26-2007, 22:09:23 GMT. Violet and gray shading represents a reflectivity value of 65 - 70 dBZ, which is a good indicator of marble to nickel size hail.

Figure 4 shows the location of the three hail monitor systems. These systems are generally deployed a few days before roll-out and retrieved a few days before launch. Due to a hazardous operation at the time of deployment for STS-134, the location of hail monitor #2 was at an alternate site, 135 ft NW of the site shown in Figure 4.

Figure 4. Location of three hail monitor stations, approximately 500 ft from pad center.

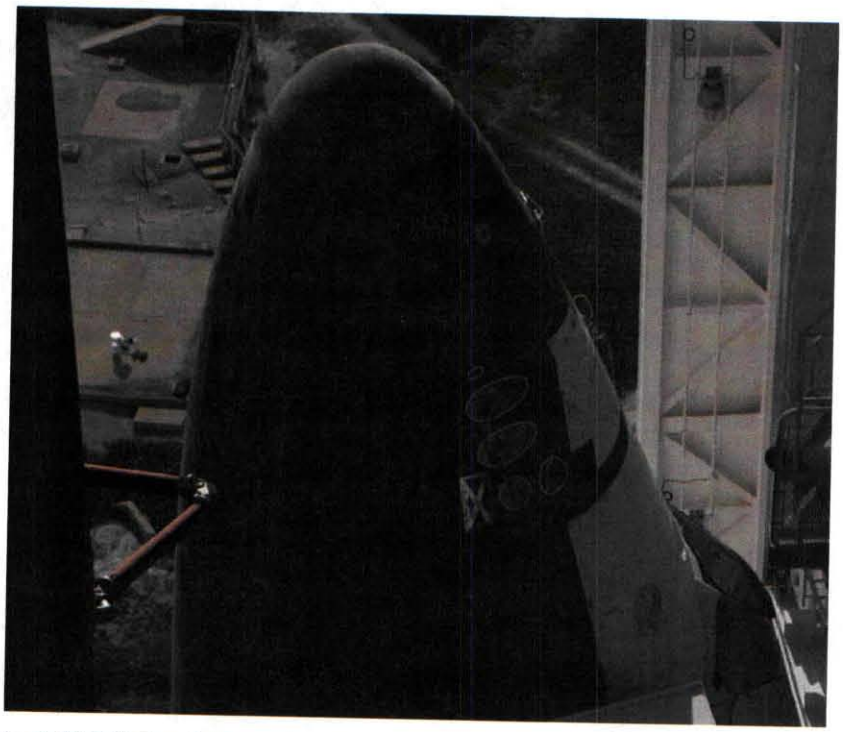

Figure 5. FSS 275 level view of hail monitor at site #1, center of left side of image.

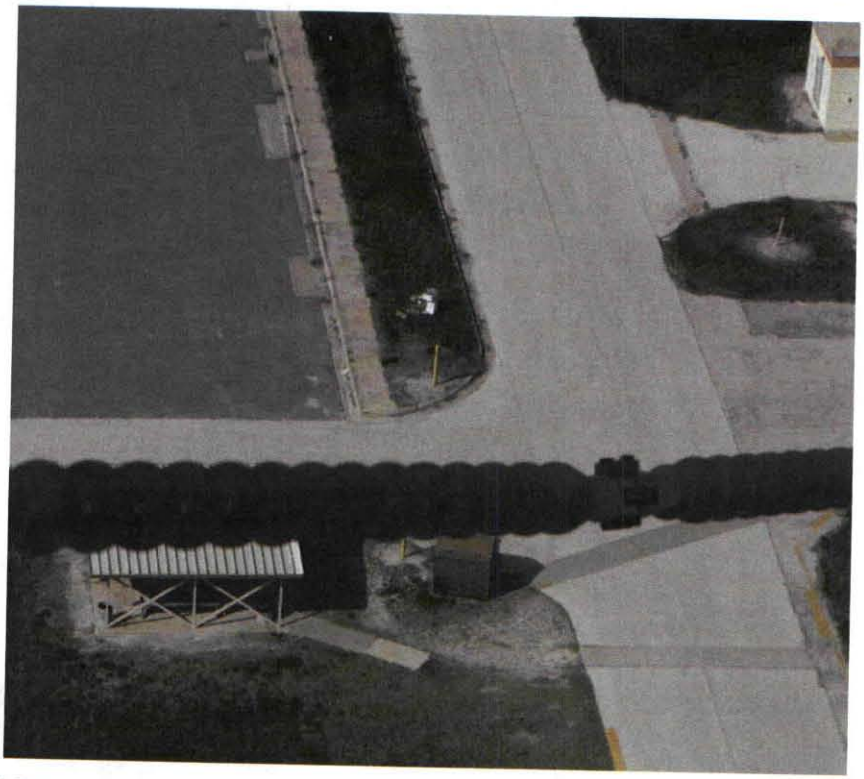

Figure 6. FSS 275 level view of hail monitor at site #2, center of image. Note dumpster and roof in lower part of image that later received extensive damaged due to high winds.

Figure 7. FSS 275 level view of hail monitor at site #3, bottom center of image.

HAIL MONITOR DATA

Site #1 (East Side):

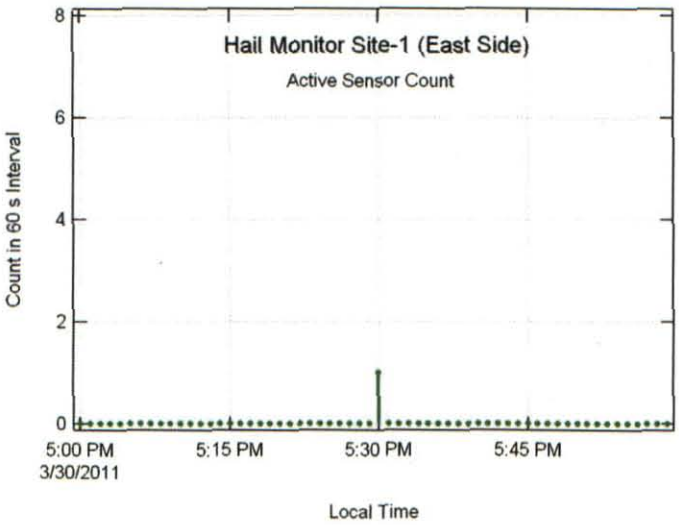

Figure 8a. Time of active sensor impulse.

Figure 8b. Passive hail pad showing small dents.

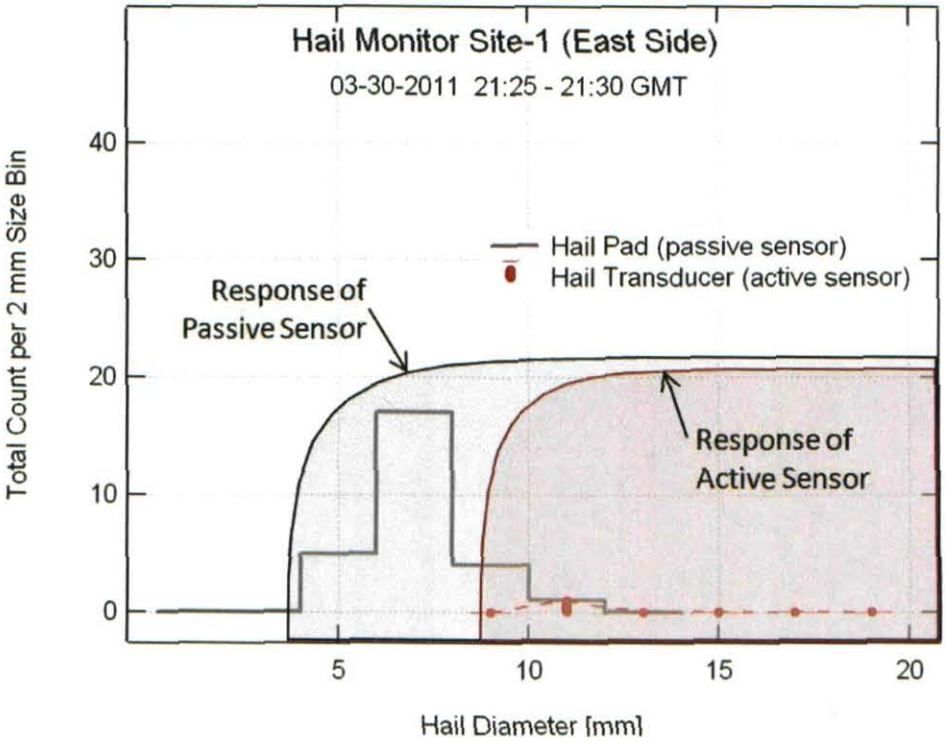

Figure 8c. Hail size histogram of both the passive and active sensors.

Site #2 (West Side):

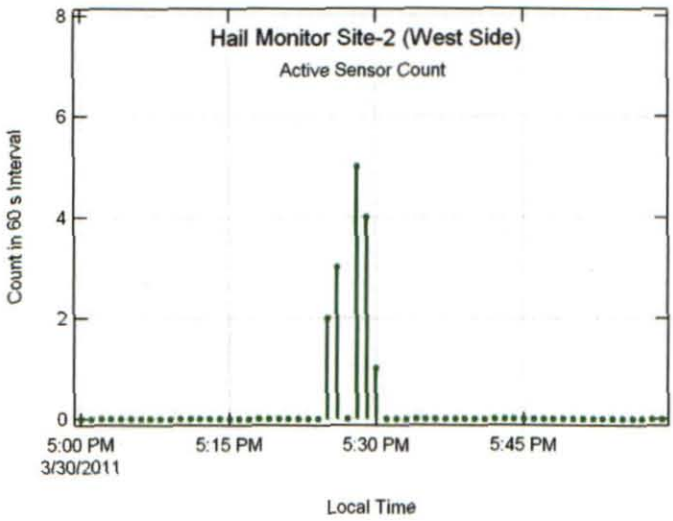

Figure 9a. Time of active sensor impulse. *Figure 9b. Passive hail pad showing small dents.*

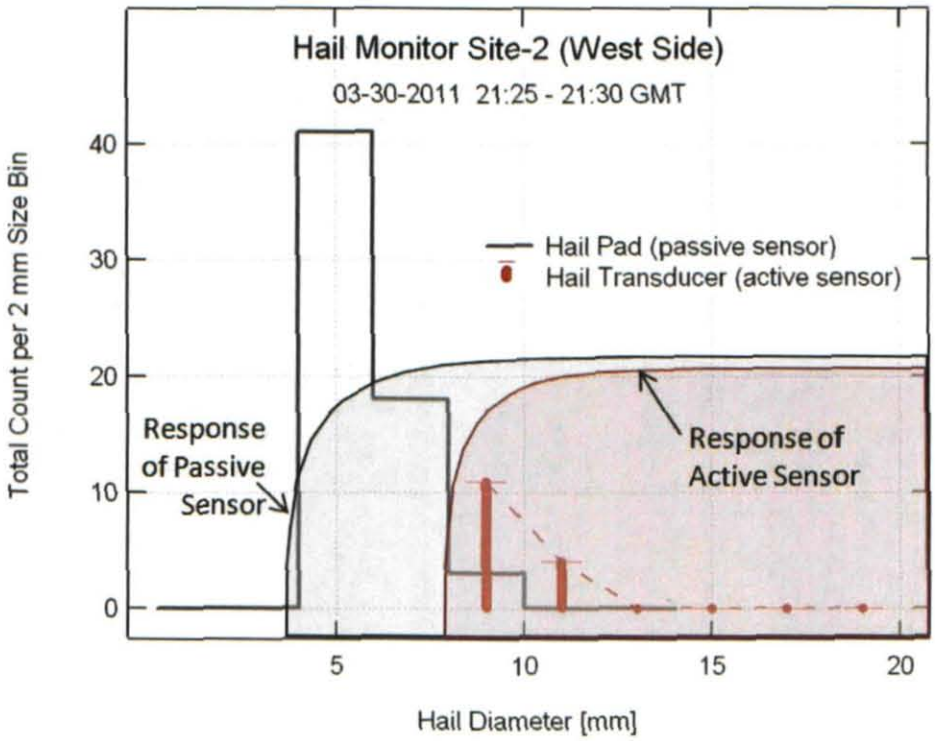

Figure 9c. Hail size histogram of both the passive and active sensors.

Site #3 (North Side):

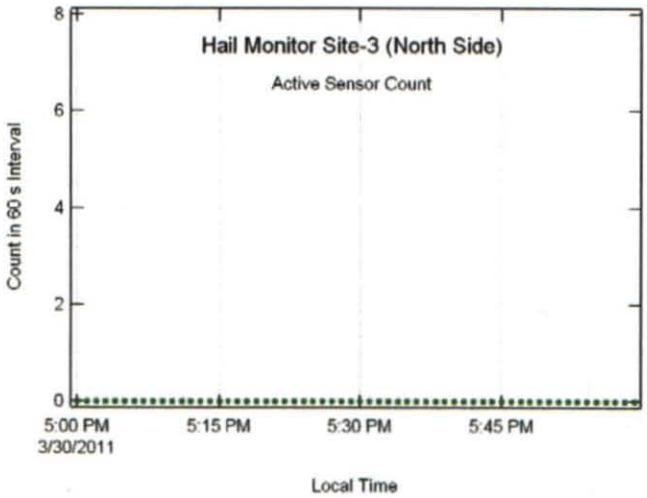

Figure 10a. Time of active sensor impulse. *Figure 10b. Passive hail pad showing small dents.*

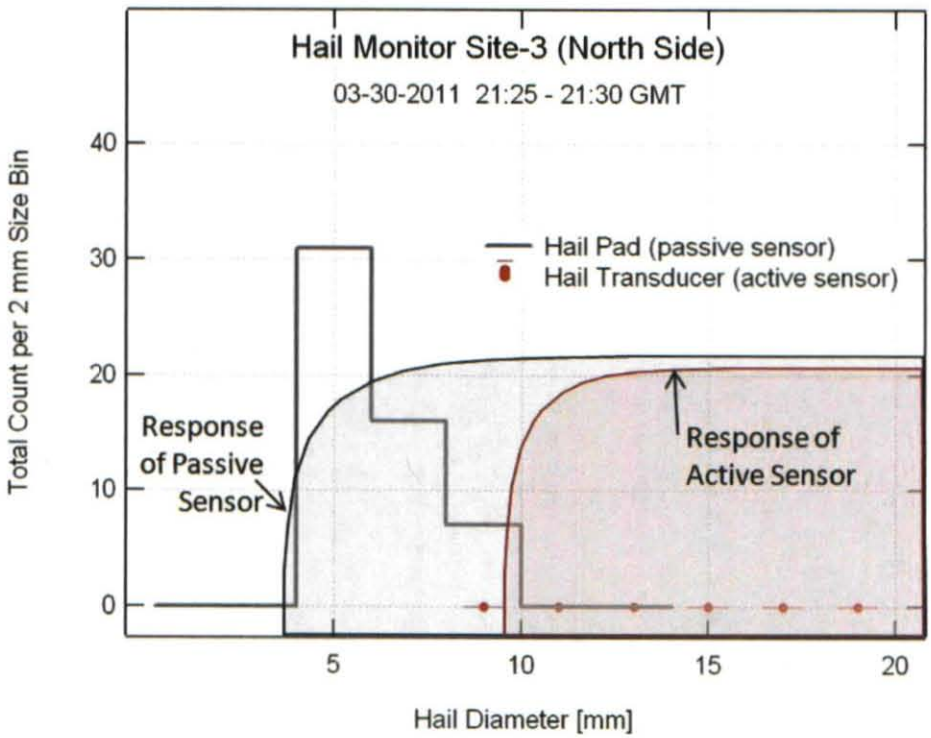

Figure 10c. Hail size histogram of both the passive and active sensors.

DISCUSSION AND SUMMARY

Site #1 on the east leeward side was shielded from the west wind by the pad structure and therefore shows a smaller total flux of hail, even though the sizes generally agree with the other two stations. Based on the behavior of the active sensor data, it would appear that the channel #1 response has drifted beyond the cut-off response of the system. This behavior can possibly be explained by weather and aging degradation of the system calibration.

Site #2 shows the most action which is expected since it received the full force of the storm on the windward side of the pad. Several impacts are counted as 10-12 mm impulses, but are likely overestimating size due to extra kinetic energy gain from the high horizontal winds.

Site #3 shows slightly larger dents in the hail pad than site #2, but no response from the active sensor. In this case, it is believed that a cable vibrated loose, resulting in no counts from the electronic sensor.

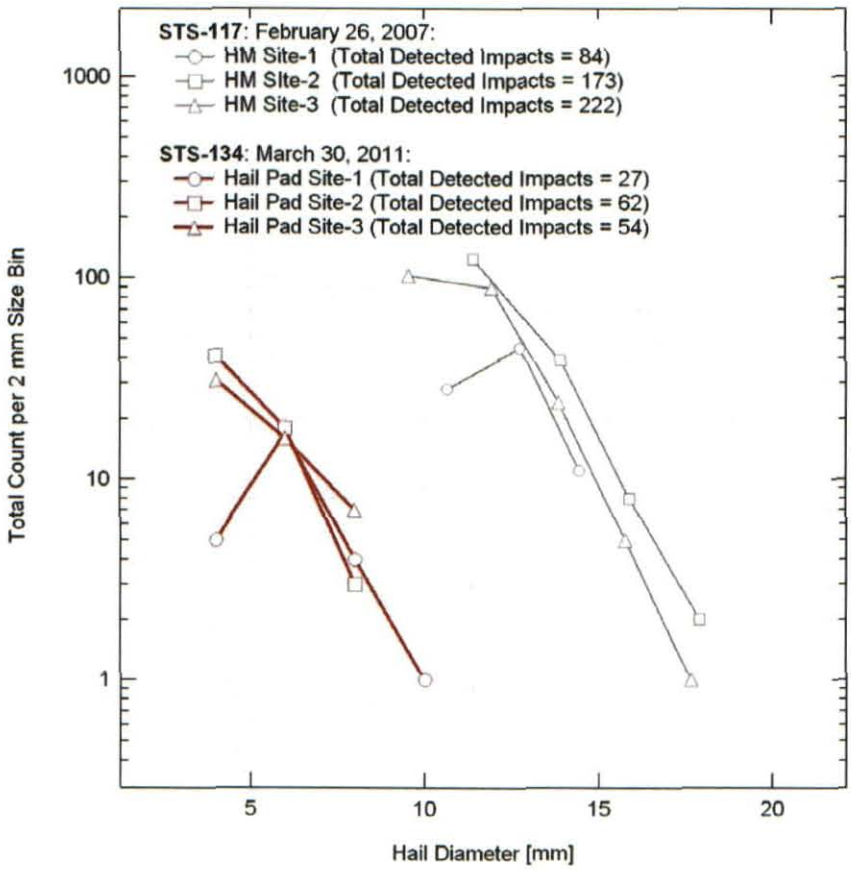

Figure 11. Hail size distributions comparing STS-134 to STS-117 events.

Figure 11 shows a comparison of the hail flux for the STS-134 event and the STS-117 event. It should be noted that counts for STS-134 hail are from the hail pads only, whereas the counts for the STS-117 hail are from the active sensor only. If the passive sensor impacts were shown, the STS-117 hail flux would be one to two orders of magnitude higher than the STS-134 counts at the low end. Since the kinetic energy of a hail impact is proportional to the mass, which is

proportional to D^3, doubling the hail size will easily increase the damage potential by a factor of eight.

The hail size and flux density for the March 30, 2011 event was minimal as compared to previous hail events. Also, the FSS was in position to block the strong west wind and the subsequent violent trajectories of hail in a horizontal direction towards the ET. Even though STS-134 has likely escaped major damage, it is probable that a few pea size hail stones made their way to impact the ET.

REFERENCES

[1] *Community Collaborative Rain and Hail Study,* Colorado Climate Center, Colorado State University, http://www.srh.noaa.gov/mlb/?n=cocorahs

[2] Strong, G.S., and E. P. Lozowski, 1977: An Alberta study to objectively measure hailfall intensity. *Atmosphere-Ocean*, **4**, 33-53.

[3] Lozowski, E. P. and G. S. Strong, 1978: On the calibration of hailpads. *J. Appl. Meteor.*, 17, 521-528.

[4] Bardsley, W. E., 1990: On the maximum observed hailstone size. *J. Appl. Meteor.*, 29, 1185-1187.

[5] Pad-39A Hail Monitor Data Analysis of the February 26, 2007 Hail Event, ASRC Aerospace, Kennedy Space Center, March 2, 2007.

[6] 3DRadPlot: Open Channel Software, http://openchannelsoftware.com/projects/3DRadPlot.

[7] Analysis of the STS-127 June 27, 2009 Hail Event, ASRC Aerospace, Kennedy Space Center, FL, July 6, 2009.