

# P220 ANALYSIS OF THE MARCH 30, 2011 HAIL EVENT AT SHUTTLE LAUNCH PAD 39A

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	2006			2007			2008			2009			2010			2011					
<b>Mission:</b>	STS-121	STS-115	STS-116	STS-117	STS-118	STS-120	STS-122	STS-123	STS-124	STS-126	STS-119	STS-125	STS-127	STS-128	STS-129	STS-130	STS-131	STS-132	STS-133	STS-134	STS-135
<b>Support:</b>		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
<b>Hail in Vicinity:</b>				✓	✓				✓		✓	✓	✓				✓		✓	✓	
<b>Hail on Pad:</b>				✓									✓			sleet	✓			✓	

Table 1. Space Shuttle launches supported by the KSC Hail Monitor system.

## 1. BACKGROUND

The Kennedy Space Center (KSC) Hail Monitor System, a joint effort of the NASA KSC Physics Lab and the KSC Engineering Services Contract (ESC) Applied Technology Lab, was first deployed for operational testing in the fall of 2006. Volunteers from the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) (Reges, 2008) in conjunction with Colorado State University have been instrumental in validation testing using duplicate hail monitor systems at sites in the hail prone high plains of Colorado.

The KSC Hail Monitor System (HMS), consisting of three stations positioned approximately 500 ft from the launch pad and forming an approximate equilateral triangle, as shown in Figure 1, was first deployed to Pad 39B for support of STS-115. Two months later, the HMS was deployed to Pad 39A for support of STS-116. During support of STS-117 in late February 2007, an unusually intense (for Florida standards) hail event occurred in the immediate vicinity of the exposed space shuttle and launch pad. Hail data of this event was collected by the HMS and analyzed (Lane, 2008).

Support of STS-118 revealed another important application of the hail monitor system. Ground Instrumentation personnel checked the hail monitors daily when a vehicle was on the launch pad, with special attention after any storm suspected of

containing hail. If no hail was recorded by the HMS, the vehicle and pad inspection team had no need to conduct a thorough inspection of the vehicle immediately following a storm. On the afternoon of July 13, 2007, hail on the ground was reported by observers at the Vehicle Assembly Building (VAB) and Launch Control Center (LCC), about three miles west of Pad 39A, as well as at several other locations at KSC. The HMS showed no impact detections, indicating that the shuttle had not been damaged by any of the numerous hail events which occurred on that day. This scenario repeated itself many times up until the last shuttle launch as shown in Table 1.



Figure 1. Location of three hail monitor stations, approximately 500 ft from launch pad center.

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## 2. STS-134 HAIL EVENT

During the late afternoon of March 30, 2011 at approximately 21:25 UTC, hail monitor stations at Pad 39A recorded pea-size hail while STS-134 Endeavour was preparing for its final flight into space. The duration of the hail event was approximately five minutes.

### 2.1 Hail Monitor System Overview

Each hail monitor system consists of two independent measurements of hail size and count (see Figure 2):

1. A *passive* hail pad - 12 [in] square Styrofoam covered with aluminum foil, where an empirical calibration curve is used to convert dent diameter to hail diameter, as shown in Figure 3 (Long, 1980; Palencia, 2011; Lozowski, 1978; Strong, 1977).
2. A 12 [in] square *active* electronic sensor (Lane, 2006) with DSP processing and six LCDs, displays accumulated counts per six size channels. Each size channel represents  $\Delta D \approx 2$  mm bin width, starting at  $D_1 \approx 9$  mm, ending with  $D_6 \geq 19$  mm.



Figure 2. Hail monitor system (HMS): (top) shows hail pad on left and active sensor on right; (bottom) shows the LCD counters for each of the six size channels.

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 diameter is less than 8 mm (low end of pea-size), the active sensor may not sense it. However the hail pads will reliably measure the impacts for hail down to the 4 mm limit.

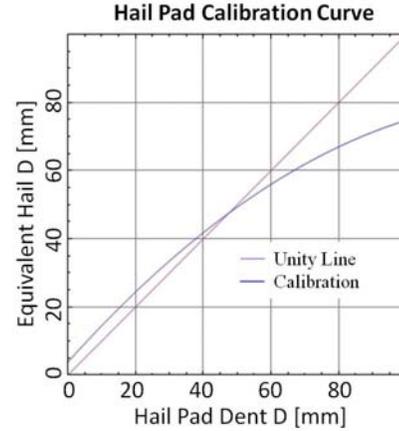


Figure 3. Hail pad calibration curve relating dent size to hail stone size.

The HMS was routinely deployed a few days before a space shuttle 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 HM-2 was at an alternate site, approximately 40 m NW of the site shown in Figure 1.

### 2.2 Hail Disdrometer

The electronic portion of the HMS is a hail disdrometer as described above. Following the March 30 event, only minimal hail counts were recorded as shown in Tables 2 and 3. The sum of the counts in corresponding columns of Tables 2 and 3 are equal:

$$\sum_j c_j = \sum_k h_k \quad , \quad (1)$$

where the sums are taken over the duration of the hail event. The total counts for at HM-1, -2, and -3 are 1, 15, and 0, respectively.

HM-1 was shielded by the pad structure, the Fixed Service Structure (FSS) and Rotating Service Structure (RSS). HM-3 was also partially shielded by the Flame Trench. HM-2 was exposed to the full approach of the storm.

Note that even though the diameters in Table 2 are shown as being equal for all three systems, in actuality, each system carries its own calibration. The calibration was originally performed using a drop tower and ice balls of known sizes. The deviation

from the integer values shown in Table 2 are no more than +/- 1 mm.

Table 2. Hail disdrometer size channel counts.

Chan, $k$	HM-1		HM-2		HM-3	
	$D_k$ [mm]	Cnt, $h_k$	$D_k$ [mm]	Cnt, $h_k$	$D_k$ [mm]	Cnt, $h_k$
1	9	0	9	11	9	0
2	11	1	11	4	11	0
3	13	0	13	0	13	0
4	15	0	15	0	15	0
5	17	0	17	0	17	0
6	$\geq 19$	0	$\geq 19$	0	$\geq 19$	0

Table 3. Hail disdrometer counts per 60 [s] interval.

Local Time $t_j$	HM-1	HM-2	HM-3
	Tot Cnt, $c_j$	Tot Cnt, $c_j$	Tot Cnt, $c_j$
17:24	0	0	0
17:25	0	2	0
17:26	0	3	0
17:27	0	0	0
17:28	0	5	0
17:29	0	4	0
17:30	1	1	0
17:31	0	0	0

### 2.3 NWS Radar

National Weather Service (NWS) NEXRAD detected and plotted the approaching hail in near real-time. Figure 4a is a base scan reflectivity plot of the NWS radar image of the March 30, 2011 storm at 21:27 UTC. Purple shows the extent of the hail swath as it approaches from the west. For comparison, the February 26, 2007 event is plotted in Figure 4b. The difference in intensity of the hail is obvious in this comparison.

#### 2.3.1 Storm Environment and Radar

On 30 March 2011, the local environment over KSC was prime for spring-time deep convection. From the hazardous weather perspective, the forecast was for strong to severe thunderstorms having the potential to produce hail at the surface along with damaging wind gusts. Central Florida was situated in a synoptic warm sector for the event as distinguished by a northward lifting warm front located across the state's panhandle with a surface low pressure system developing over lower Mississippi and an associated cold front extending outward over the Gulf of Mexico. Atmospheric destabilization was promoted by low level temperature and moisture advection from South Florida in concert with daytime solar heating. By the afternoon, dew point temperatures would be in the upper 60s to lower 70s (deg F) area-wide. Deep layer shear increased with the progression of the day peaking to 40-50 kt through the bottom half of the atmosphere. The atmosphere possessed sufficient directional shear to support moderately rotating updrafts, but steady veering with time of the low level wind flow would transition the main threat from

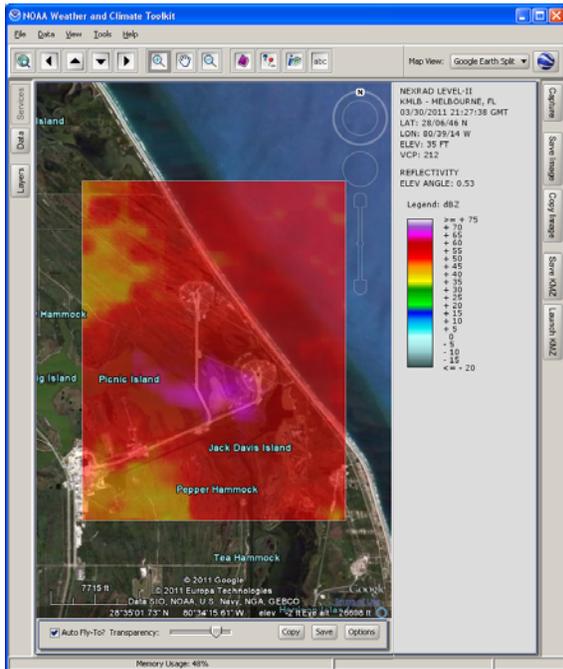


Figure 4a. NWS radar image of March 30, 2011 storm. Purple shows the extent of the hail swath as it approached from the west.

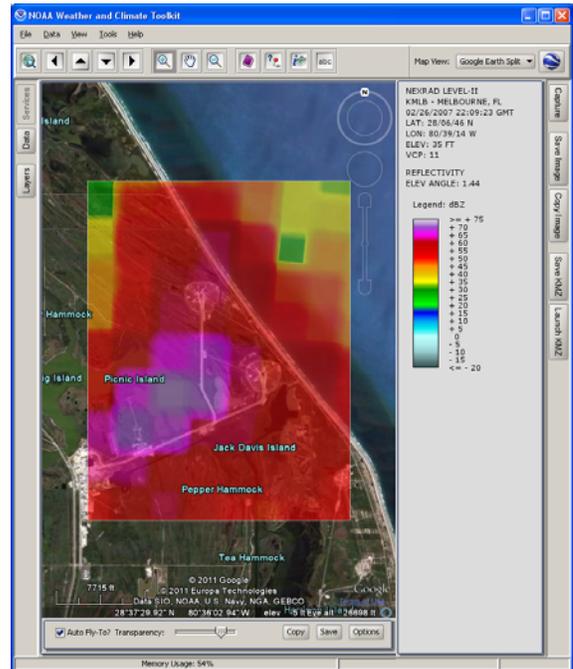


Figure 4b. NWS radar image of February 26, 2007 storm. Purple and grey shows the hail swath as it approached from the west.

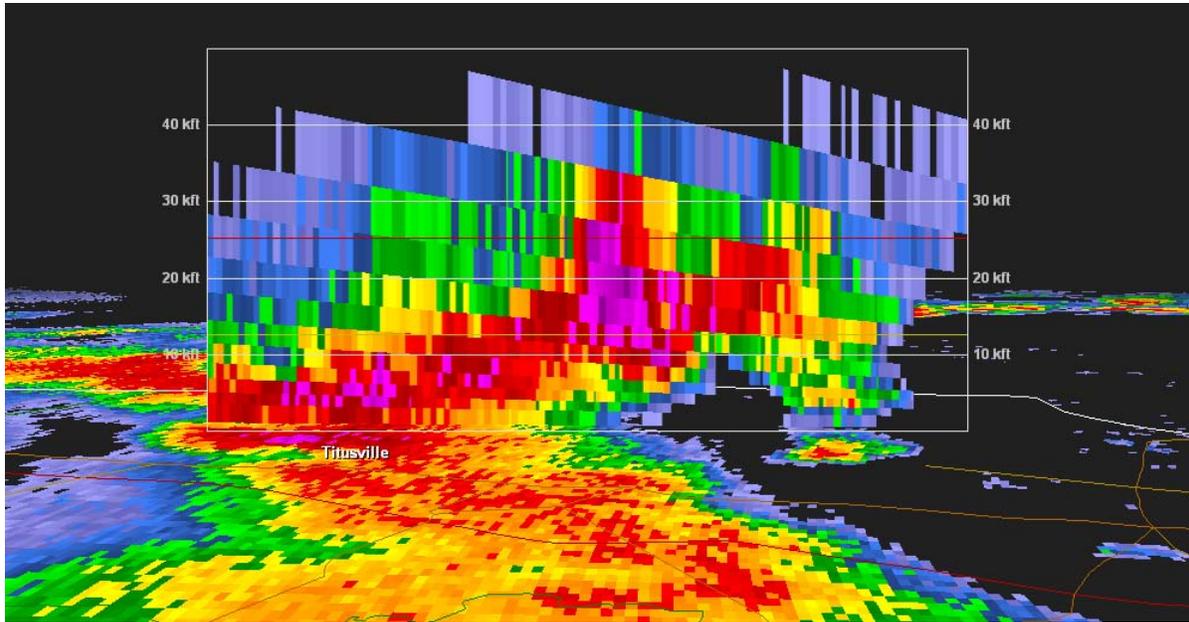


Figure 4c. The viewing angle of the image is from the inland direction (origin west of Titusville and KSC) looking east (into the image). Note the hail (very high dBZ; purple) descending to the surface near Titusville, and the elevated hail aloft (between 10-30 kft) extending NW-SE from near Titusville toward KSC (aloft).

isolated tornadoes to straight-line damaging winds and large hail late in the event. A Tornado Watch was in effect from late morning through 8 PM, to include KSC.

By 2100 UTC, the National Weather Service radar (located 55 km south of Pad 39A at the Melbourne International Airport) indicated that a line of strong to severe storms had developed and was approaching northern Brevard County from the west and northwest. Reports of large hail (quarter-size; ~25 mm) were reported at several inland locations during the previous hour as the line approached. At 2115 UTC, large hail was reported on the ground in Titusville (located in Brevard County), and at 2119 UTC a severe wind gust to 74 kt was measured by the KSC wind tower network (tower 0421; 54 ft). Figure 4c shows the radar reflectivity cross-section of associated high dBZ returns (60-65 dBZ) lowering to the surface at Titusville, with an elevated hail core overhanging parts of the KSC complex. Figure 4a is a base reflectivity plot (0.5 deg) highlighting where (wetted) hail was reaching the surface by 2127 UTC. The purple area generally outlines the surface footprint of large hail in close proximity to the launch pad at that time, but with lesser dBZ returns over the site itself suggesting small hail was occurring there. For comparison, the 26 February 2007 hail event is plotted in Figure 4b with the reflectivity near 70 dBZ.

## 2.4 Hail Pads

Because of the high winds associated with the passage of this storm, and the fact that hail was detected at the launch pad by the hail monitor system, as well as NWS radar, a thorough analysis of the hail

pads at each station was then performed. Figures 5 show the view of the hail monitor sites from the Fixed Service Structure (FSS). Figure 6 are images of the hail pads at each site, after the hail event. Inspection of the hail pads reveals numerous dents from very small to something approaching to 0.5 [in]. Most of the hail size data associated with this event is contained in the hail pads.

Table 4. Hail pad counts.

Bin, $i$	$D_i$ [mm]	Cnt, $H_i$		
		HM-1	HM-2	HM-3
8	3.75	0	0	0
9	4.25	0	2	0
10	4.75	1	11	6
11	5.25	2	12	17
12	5.75	2	16	8
13	6.25	6	8	5
14	6.75	2	5	5
15	7.25	6	3	3
16	7.75	3	2	3
17	8.25	3	0	1
18	8.75	0	2	4
19	9.25	1	0	2
20	9.75	0	1	0
21	10.25	0	0	0
22	10.75	0	0	0
23	11.25	0	0	0
24	11.75	1	0	0
25	12.25	0	0	0



*Figure 5. FSS 275 level view of: (top) HM-3, bottom center of image; (middle) HM-2, center of image; (bottom) HM-1, center of left side of image.*

*Figure 6. Passive hail pad showing small dents: (top) HM-3; (middle) HM-2; (bottom) HM-1.*

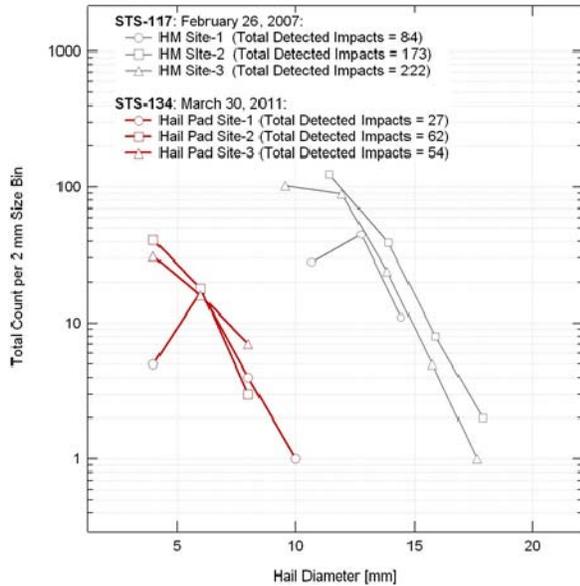


Figure 7. Hail size distributions comparing STS-134 to STS-117 events.

Table 4 tabulates the result of counting hail pad dents and converting to equivalent hail stone diameter using the calibration from Figure 3. A custom image processing program was used measure and log the hail dents in the foil images.

The histogram data from Table 4 can then be plotted with the hail disdrometer data from the STS-117 event for comparison, as shown in Figure 7. Note that the bin size is changed in Table 4 from  $\Delta D = 0.5$  mm to  $\Delta D = 2$  mm in order to properly compare to the hail disdrometer data of February 26, 2007.

Figure 8 shows a set of histogram plots for all three systems, comparing the passive hail pad counts to the active disdrometer counts. Upon examining the histograms of Figure 8, it can be seen that the hail pad and disdrometer histograms don't quite line up. One explanation for this is aging of the active sensor which then affects the response. A correction should be applied to the disdrometer calibration as follows: HM-1, no correction; HM-2 shift down by 1 mm; HM-3 shift up by 1 mm.

### 3. SUMMARY

The maximum hydrometeor size, of the STS-134 March 30 event, detected by the composite measurement of the three hail disdrometers and three hail pads surrounding the launch pad structure was estimated to be no larger than 12 mm, corresponding to the 6 sq. ft. total sensor measurement area. The 12 mm maximum size was measured by the active impact sensor at Station-2, located on the west side of the shuttle launch pad. High winds from the west produced a few elongated dents in the hail pads. High winds were also responsible for damage to facilities

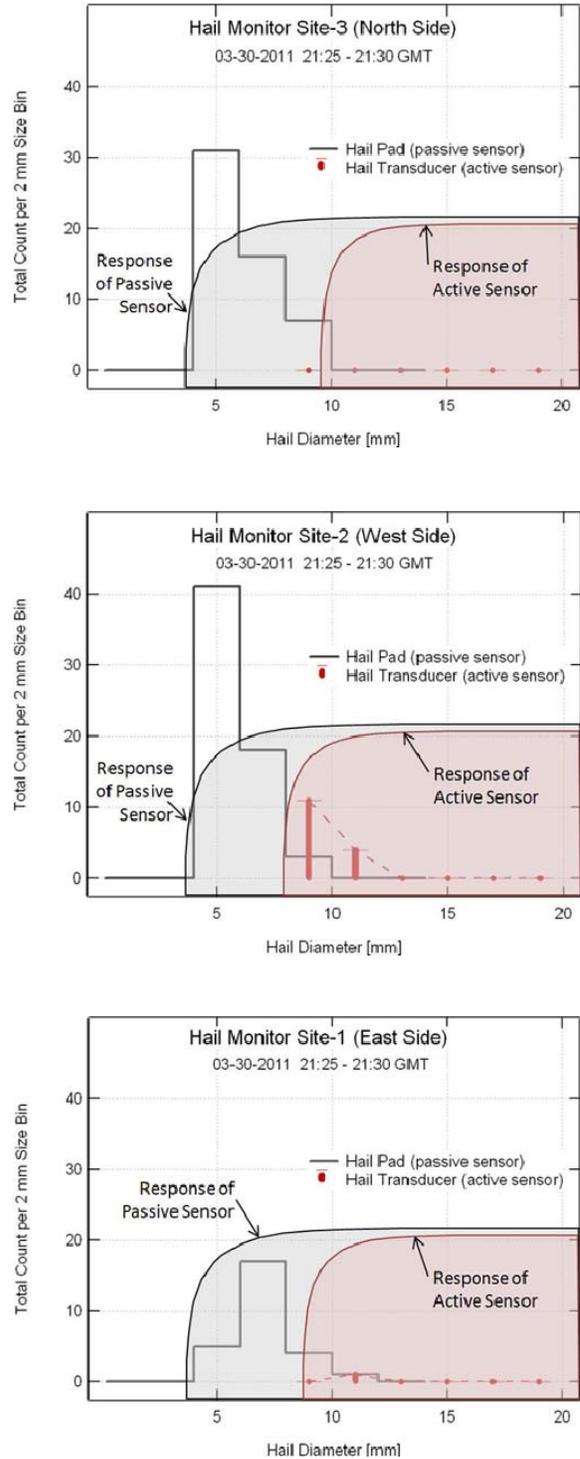


Figure 8. Hail size histograms from HMS: (top) HM-3; (middle) HM-2; (bottom) HM-1.

near hail monitor Site-2, where a dumpster was overturned and a picnic table roof was demolished. NWS radar volume scan showed 60-65 dBZ reflectivity values in the lowest four scan elevations

around and over the pad 39A area. 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, consistent with partial melting before reaching the shuttle's fragile external tank outer shell.

Pea-sized hail is about 6-12 mm (~1/4 inch, but less than 1/2 inch). Large hail is now about 25 mm (~1 inch) to be considered severe; in 2007 (for previous event) the original definition was in place at about 18-20 mm (~3/4 inch). It seems the large hail just missed Pad 39A. The hail that did strike the pad (and HMS) was likely rain-wetted and melting as it fell. Wetted hail stones are very highly reflective.

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 escaped major damage, it is probable that a few pea-size hail stones made their way to impact the ET.

Following inspection of the external tank and the Orbiter's thermal protection system, it was determined that repair was not necessary and launch preparations were continued for the final flight of space shuttle Endeavour.

With Dual Pol functionality now at the 45WS and soon to be at NWS/MLB, we'll have advantages toward discerning hail size; there will exist obvious opportunity to perform important Florida hail studies in a way that hasn't been done before.

#### 4. REFERENCES

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