

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

John E. Lane*
 Easi-ESC, Kennedy Space Center, FL, USA
 Nolan J. Doesken
 Colorado State University, CO, USA
 Takis C. Kasparis
 Cyprus University of Technology, Lemesos, Cyprus
 David W. Sharp
 National Weather Service, Melbourne, FL, USA

	2006			2007			2008			2009			2010			2011					
Mission:	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
Support:		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hail in Vicinity:				✓	✓				✓		✓	✓	✓				✓		✓	✓	✓
Hail on Pad:				✓									✓			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 check the hail monitors daily when a vehicle is on the launch pad, with special attention after any storm suspected of containing hail.

If no hail is recorded by the HMS, the vehicle and pad inspection team has 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 Vertical 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.

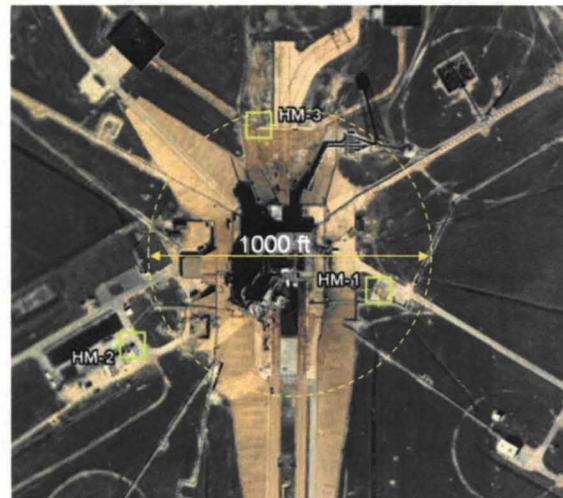


Figure 1. Location of three hail monitor stations, approximately 500 ft from launch pad center.

* Corresponding author address: Easi-ESC, MS: ESC-24, Kennedy Space Center, FL 32899, 321-867-6939; e-mail: John.E.Lane@nasa.gov.

2. STS-134 HAIL EVENT

During the late afternoon of March 30, 2011 at approximately 21:25 GMT, 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 $\Delta D = 2$ mm bin width, starting at $D_1 \approx 9$ mm, ending with $D_6 \geq 19$ mm.

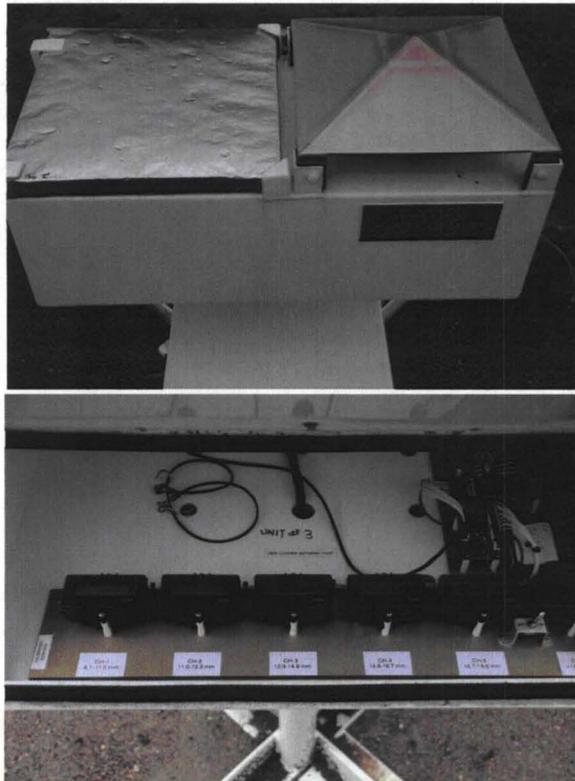


Figure 2. Hail monitor system (HMS): (top) shows hail pad on left and active sensor on right; (bottom) shows the LCD counters for each of the six size channels.

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 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 the 4 mm limit.

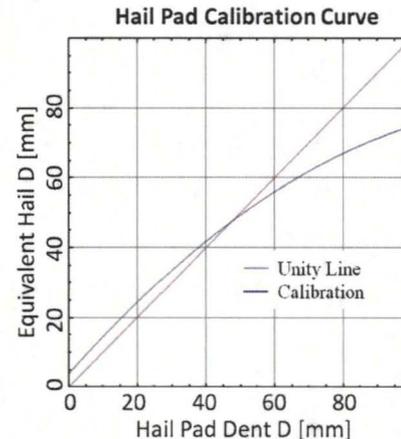


Figure 3. Hail pad calibration curve relating dent size to hail stone size.

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:

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

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	≥ 19	0	≥ 19	0	≥ 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, located 55 km south of Pad 39A at the NW corner of the Melbourne International Airport, 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 GMT. 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.

2.4 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 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.

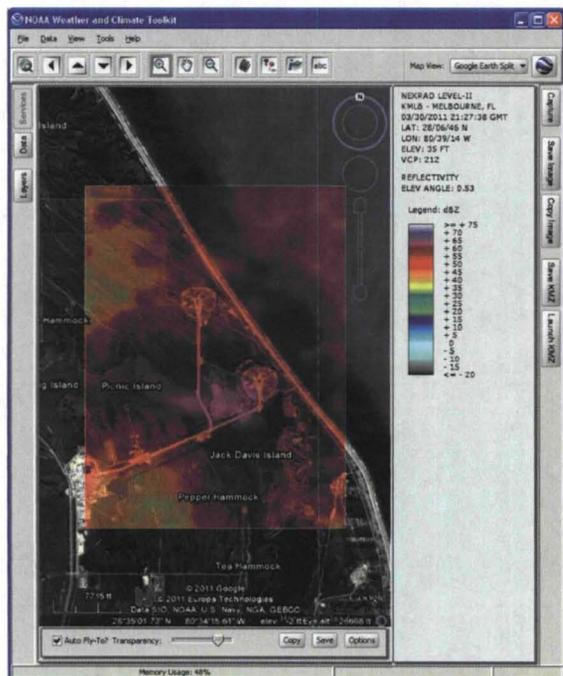


Figure 4a. NWS radar image of March 30, 2011 storm. Purple shows the extent of the hail swath as it approached from the west.

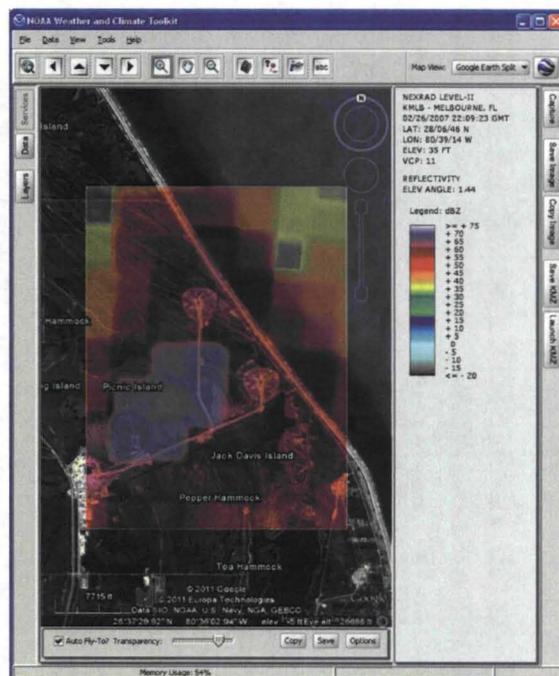


Figure 4b. NWS radar image of February 26, 2007 storm. Purple and grey shows the hail swath as it approached from the west.

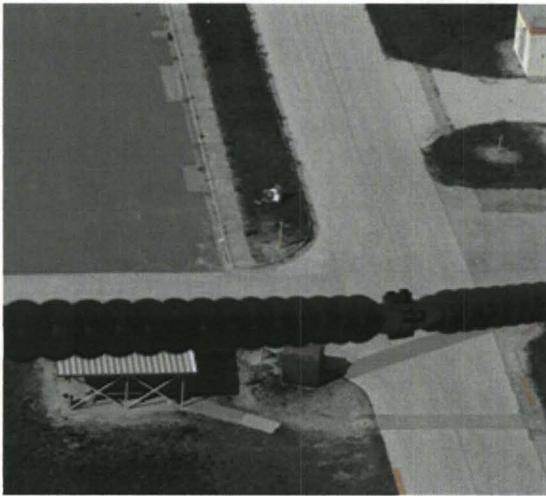


Figure 5. FSS 275 level view of: (top) HM-3, bottom center of image; (middle) HM-2, center of image; (bottom) HM-1, center of left side of image.

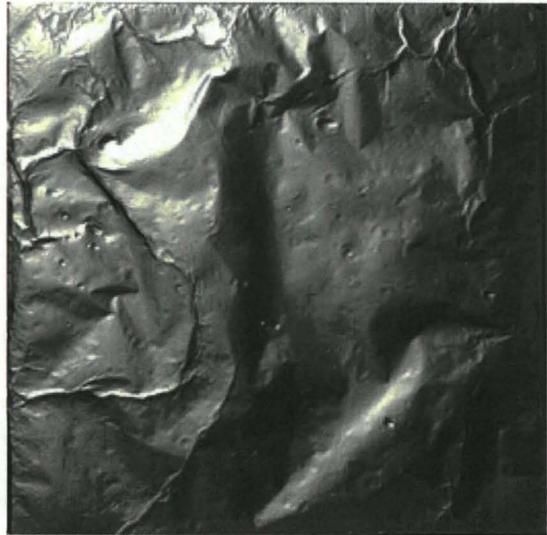


Figure 6. Passive hail pad showing small dents: (top) HM-3; (middle) HM-2; (bottom) HM-1.

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

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.

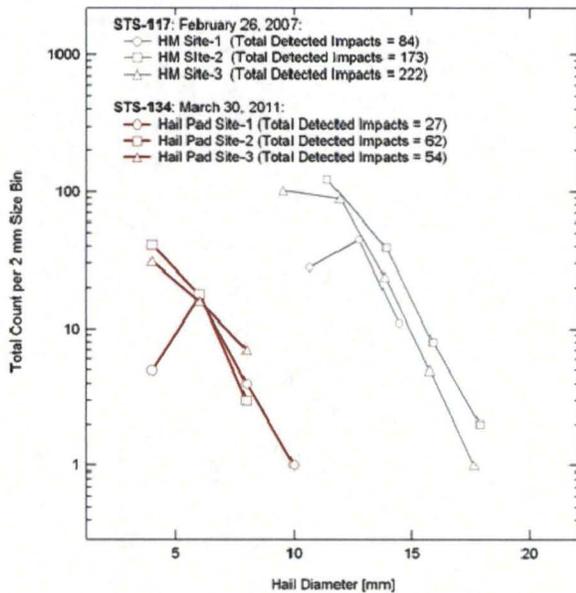


Figure 7. Hail size distributions comparing STS-134 to STS-117 events.

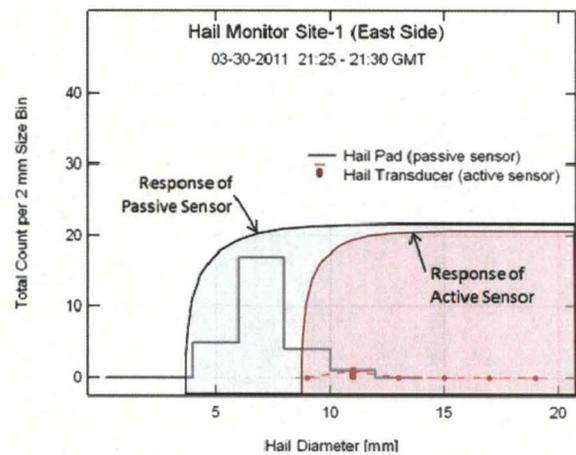
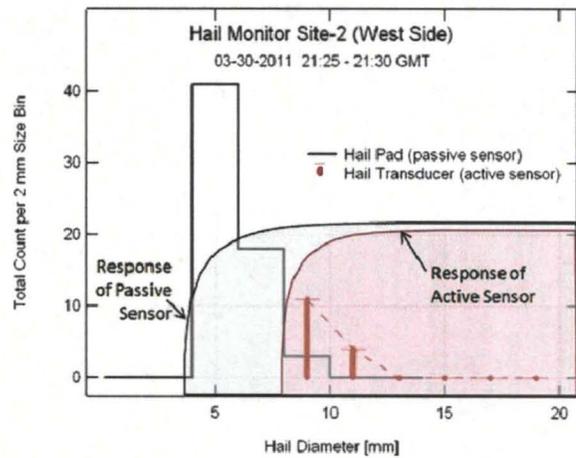
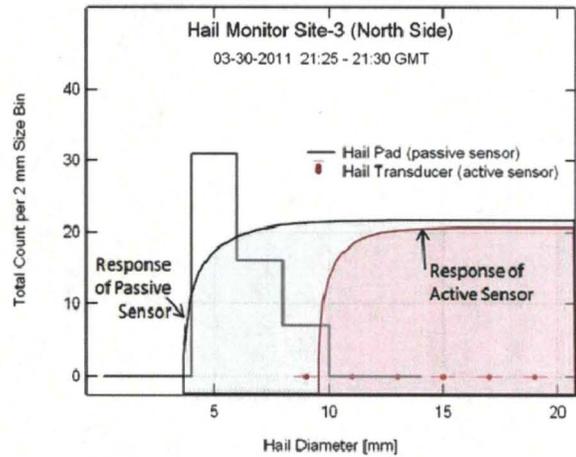


Figure 8. Hail size histograms from HMS: (top) HM-3; (middle) HM-2; (bottom) HM-1.

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 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.

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.

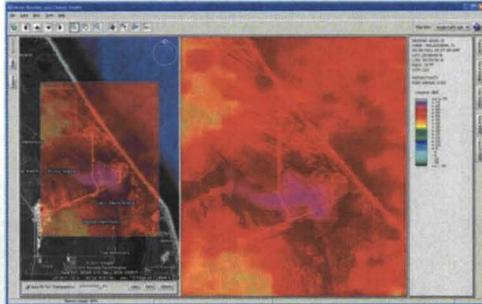
Following inspection of the external tank and the Orbiter's thermal protection system, it was determined that repair was not necessary and launch preparations were continued for the final flight of space shuttle Endeavour.

4. REFERENCES

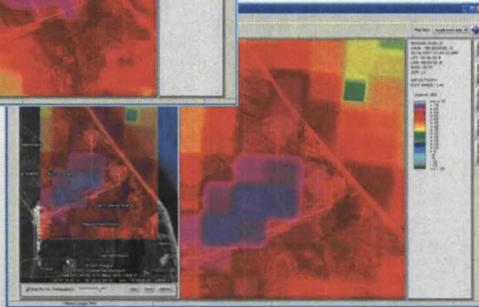
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P220: Analysis of the March 30, 2011 Hail Event At Shuttle Launch Pad 39A

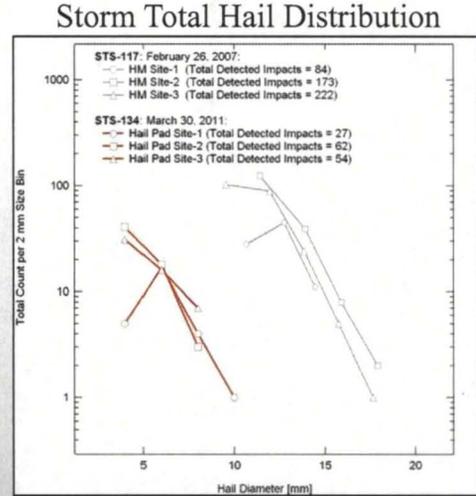
John E. Lane, Easi-ESC, Kennedy Space Center, FL
 Nolan J. Doesken, Colorado State University, Ft. Collins, CO
 Takis C. Kasparis, Cyprus University of Technology, Lemesos, Cyprus
 David W. Sharp, National Weather Service, Melbourne, FL



STS-117 Event
 (February 26, 2007)

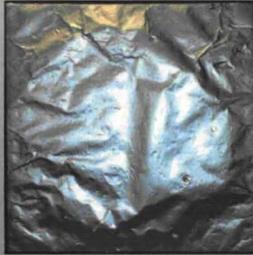


STS-134 Event
 (March 30, 2011)

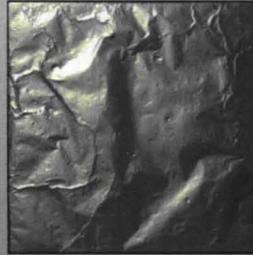


- During the late afternoon of March 30, 2011 at approximately 21:25 GMT, hail monitor stations at Pad 39A recorded pea size hail while STS-134 Endeavour was preparing for its final flight into space.
- The maximum hydrometeor size detected by the composite measurement of the three hail disdrometers 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.
- Damage to external tank was minimal and repair was not required.

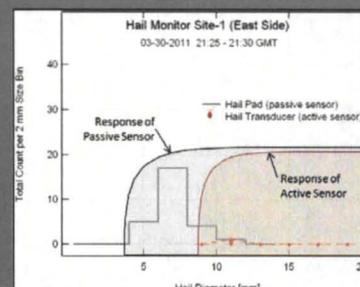
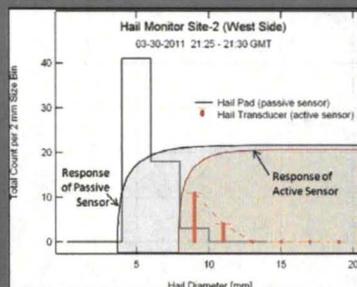
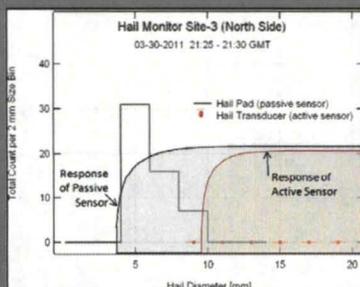
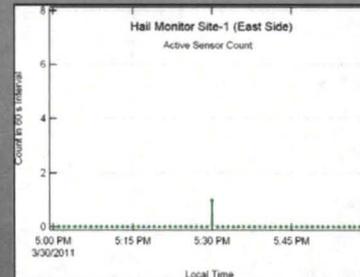
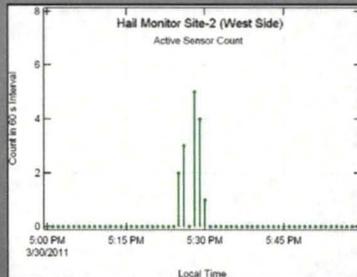
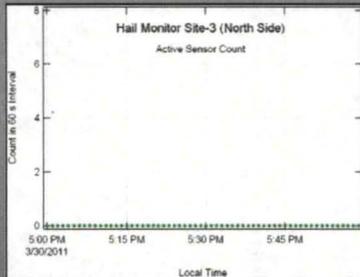
Site-3 Hail Pad



Site-2 Hail Pad

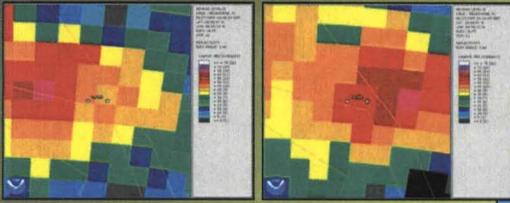


Site-1 Hail Pad



STS-127 Event - June 27, 2009

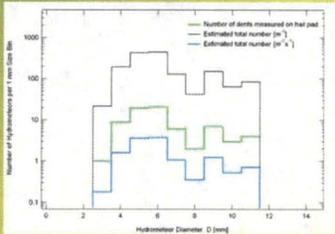
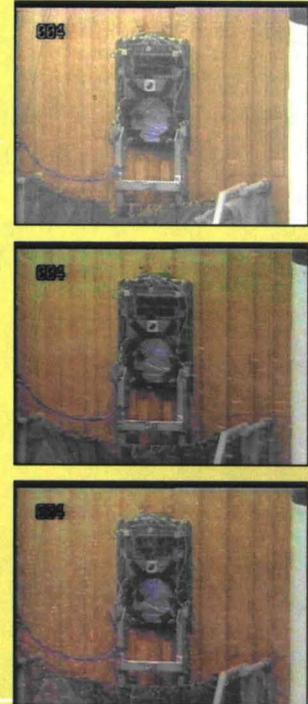
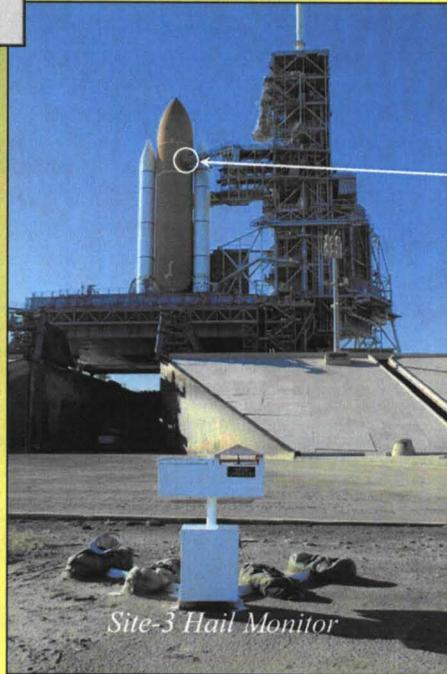
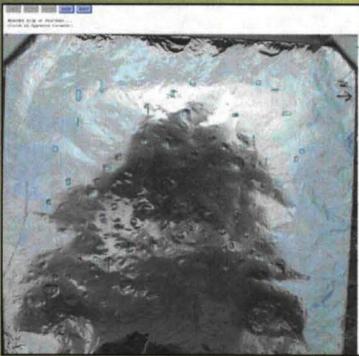
Melbourne NEXRAD



- Hail pad dents indicate very large raindrops.
- Consistent with the occurrence of slushy low density hail.
- No damage to vehicle occurred.

GUCP inspection camera showed what appeared to be hail

Site-3 Hail Pad



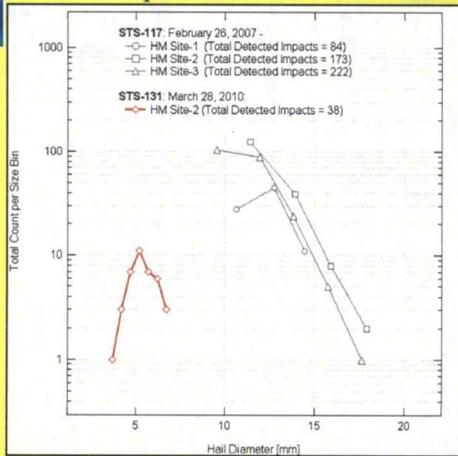
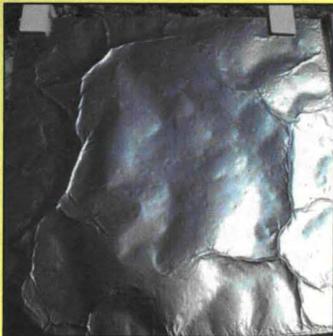
Site-3 Hail Pad Histogram

STS-131 Event - March 28, 2010

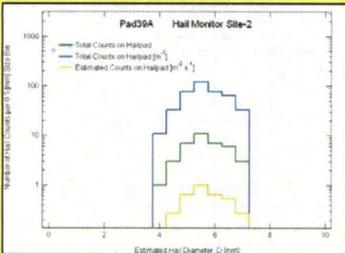
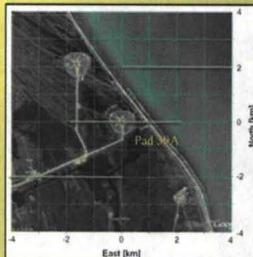
- Small hail and low count.
- No damage to vehicle occurred.

Comparison to STS-117

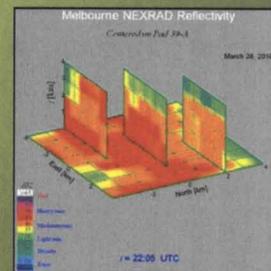
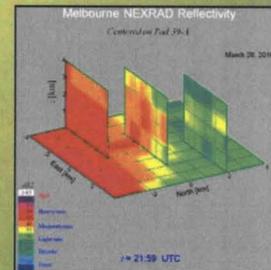
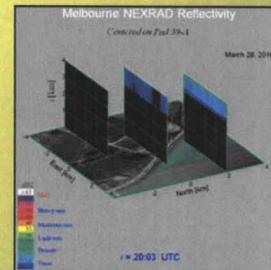
Site-2 Hail Pad



Pad 39A



Site-2 Hail Pad Histogram



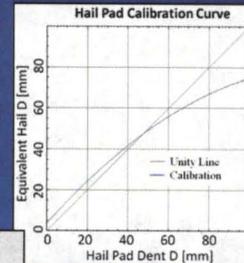
KSC Hail Disdrometer for Space Shuttle Operations

Total Missions Supported

Mission:	2006			2007			2008			2009			2010		2011							
	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	
Support:	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hail in Vicinity:	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hail on Pad:			✓										✓			sleet	✓				✓	✓



Hail Impact Transducer



Hail Disdrometer



Hail Pad Calibration

Diameter Size Displays

Hail Monitor System – Pad 39A

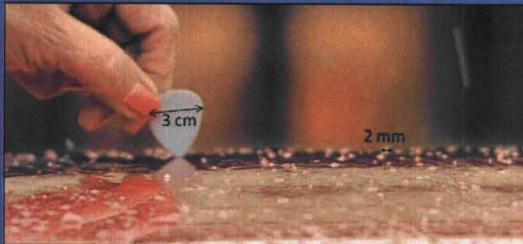
Kennedy Space Center, FL



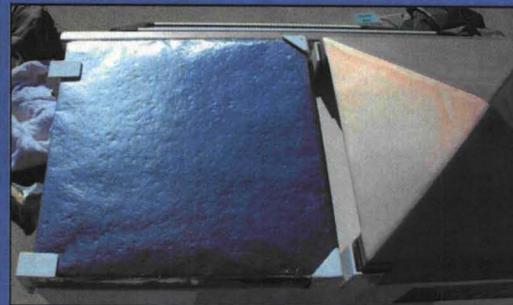
STS-130 Event - January 9, 2010

- Small sleet pellets.
- No damage to vehicle occurred.

Sleet Event



Site-1 Hail Pad



Site-2 Hail Pad



Site-3 Hail Pad

