

# Harvey Rainfall and Probable Maximum Precipitation-What Happened and How Does It Compare

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Applied Weather Associates (AWA)

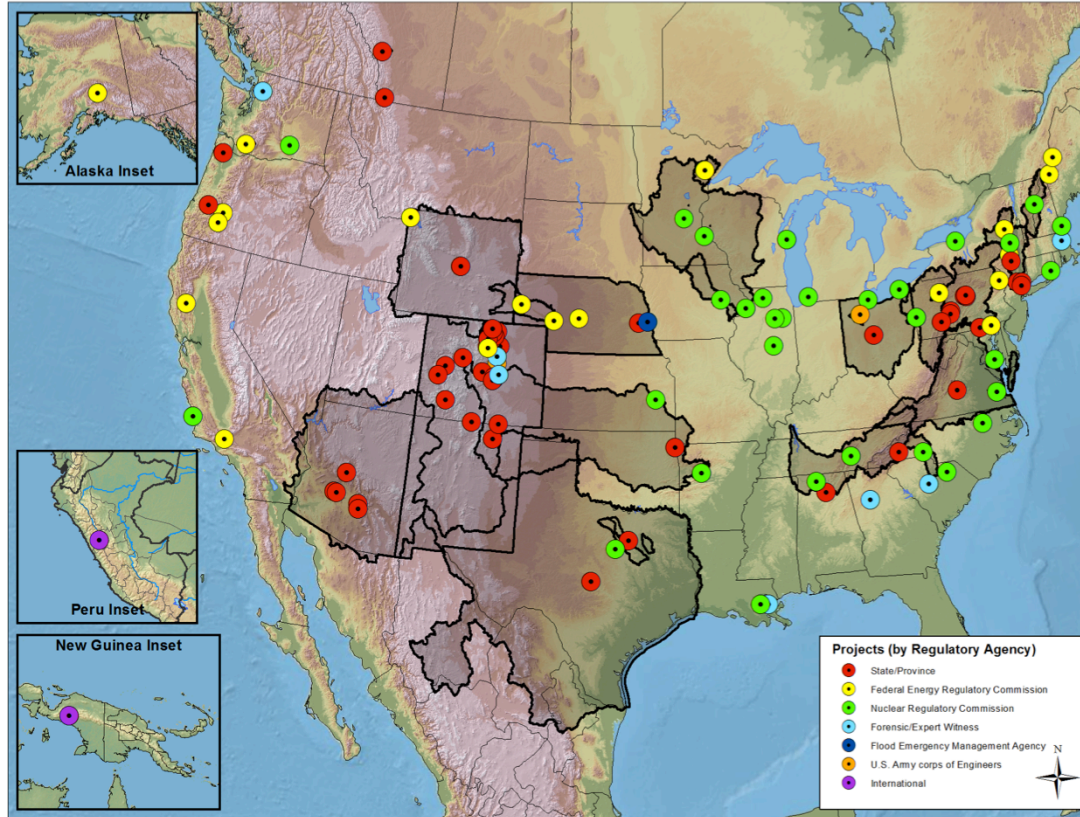
719-488-4311, [billkappel@appliedweatherassociates.com](mailto:billkappel@appliedweatherassociates.com)



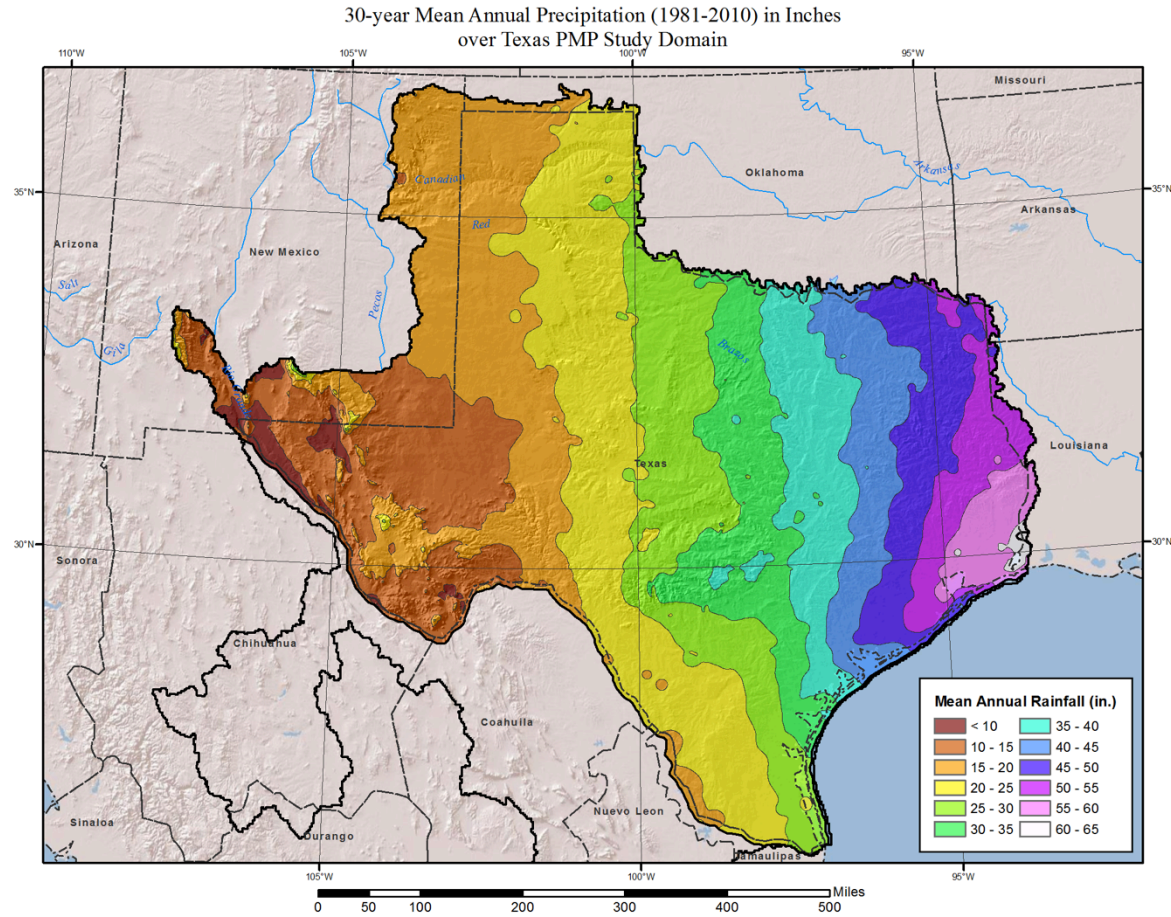
# Probable Maximum Precipitation

**Definition:** The theoretically greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographic location at a certain time of year (HMR 59, 1999)

# AWA Probable Maximum Precipitation Studies

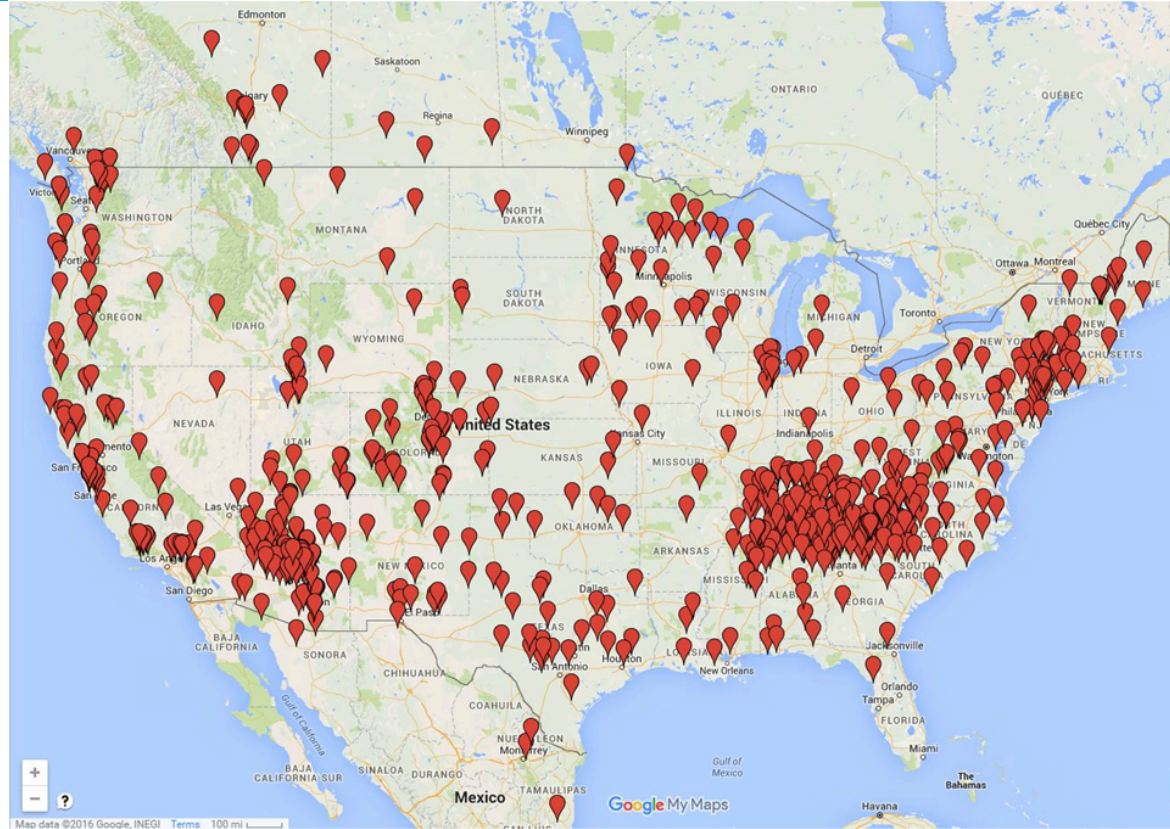


# Texas Mean Annual Precipitation

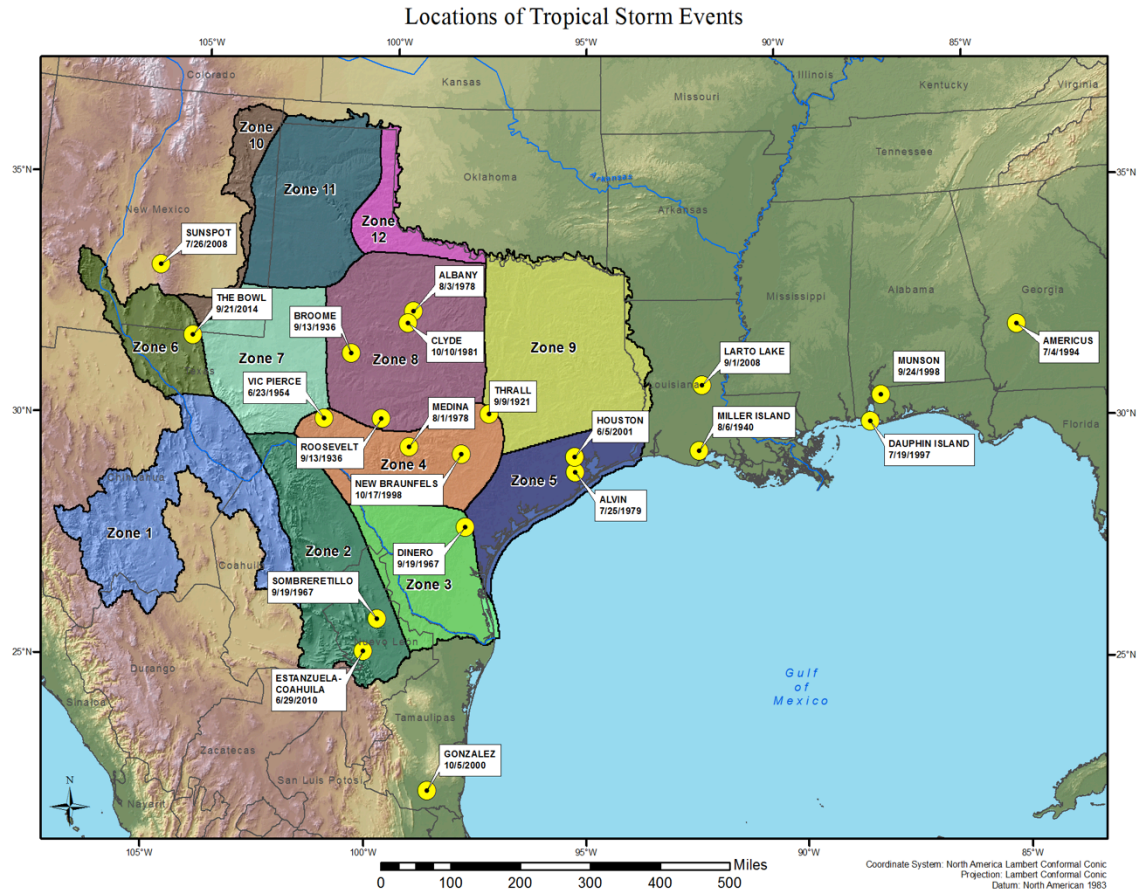




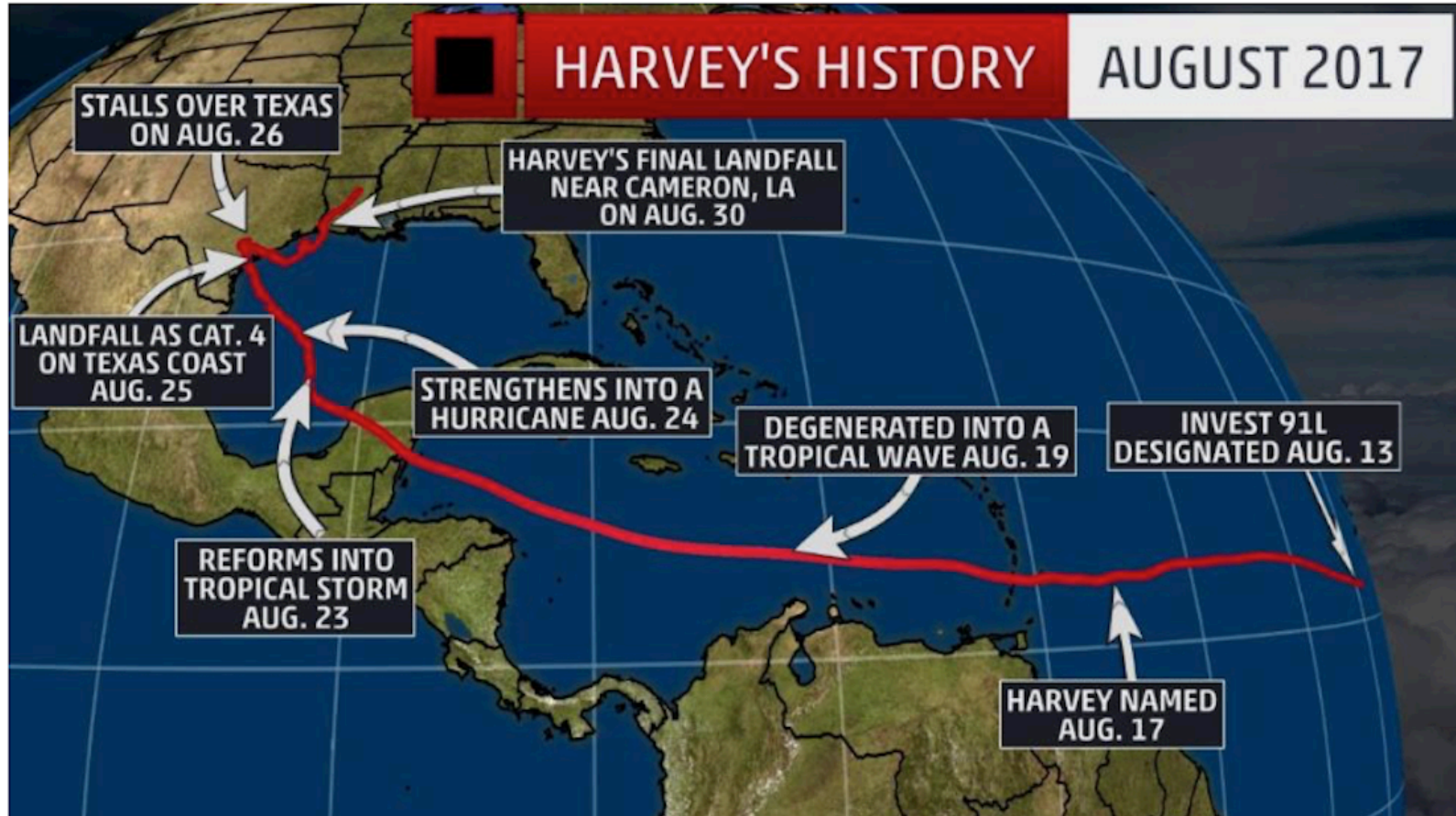
# Probable Maximum Precipitation – Storm Search



# Tropical storm locations



# Harvey's Path to Texas

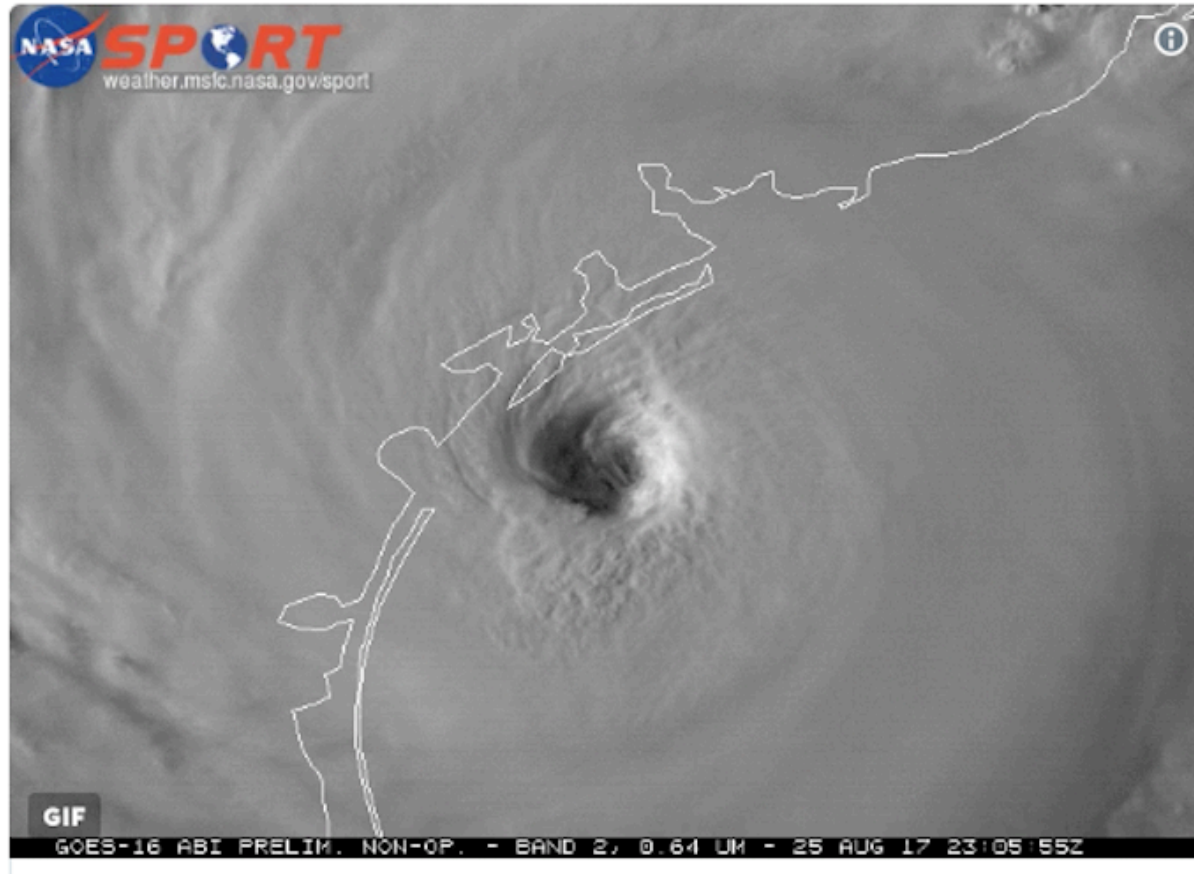




# Harvey over the Houston Area

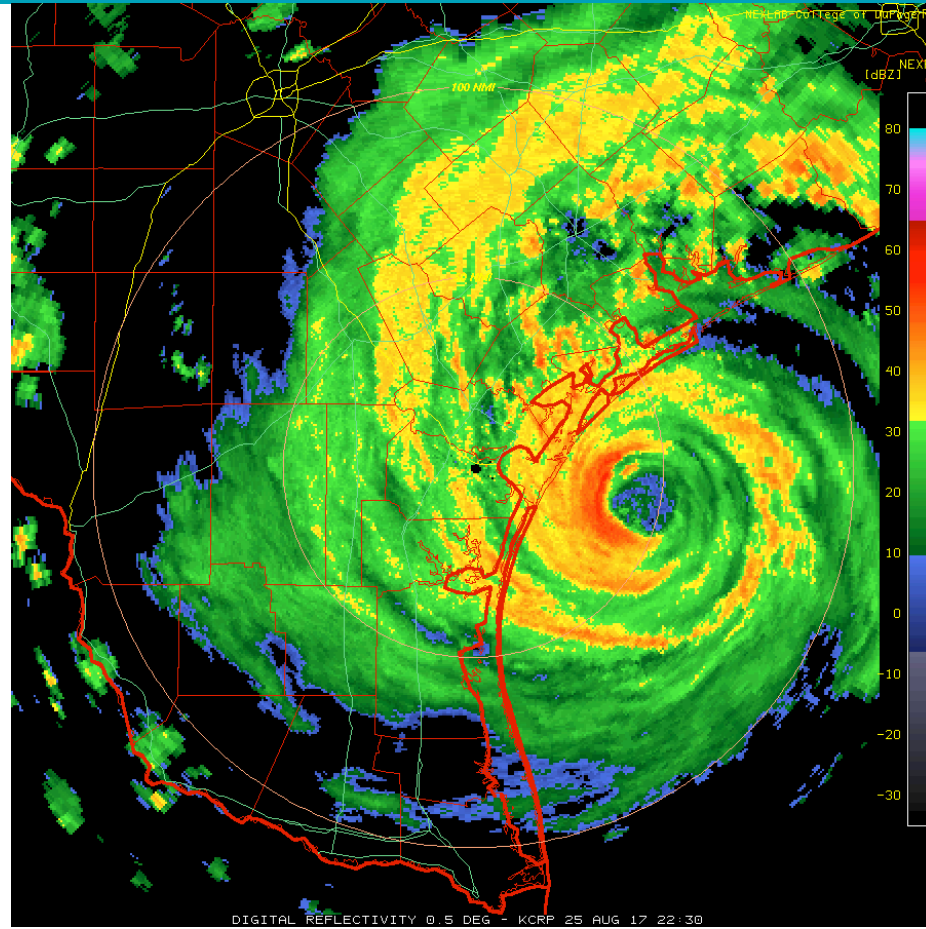


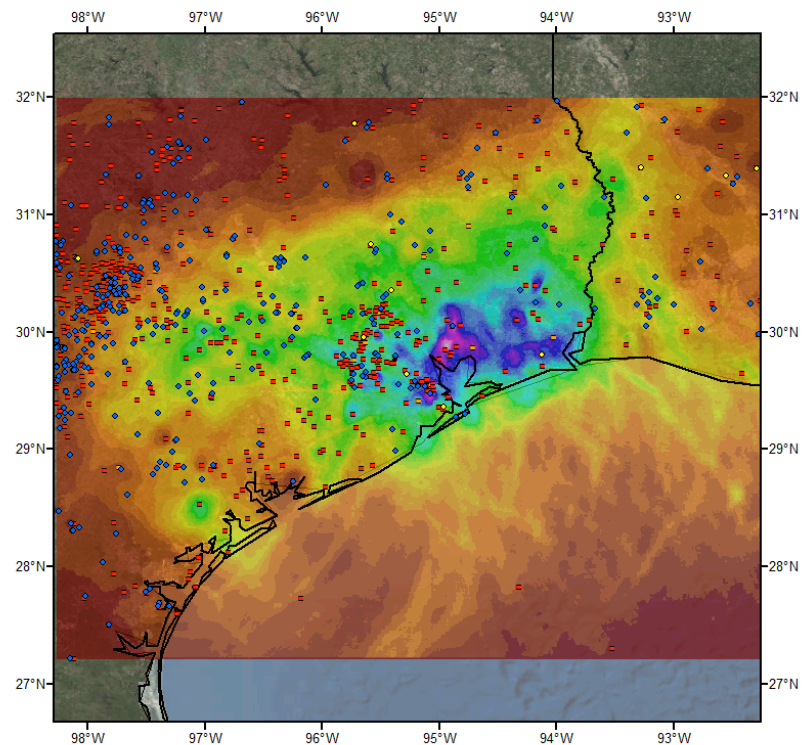
# Visible Satellite Image of Harvey at Landfall





# Radar Loop of Harvey





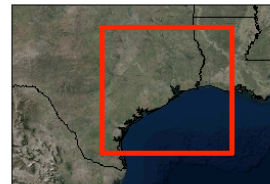
**Total Storm (156-hr) Precipitation (inches)**  
**8/25/2017 0700 UTC - 8/31/2017 1800 UTC**  
**SPAS-NEXRAD 1667 (Prelim)**

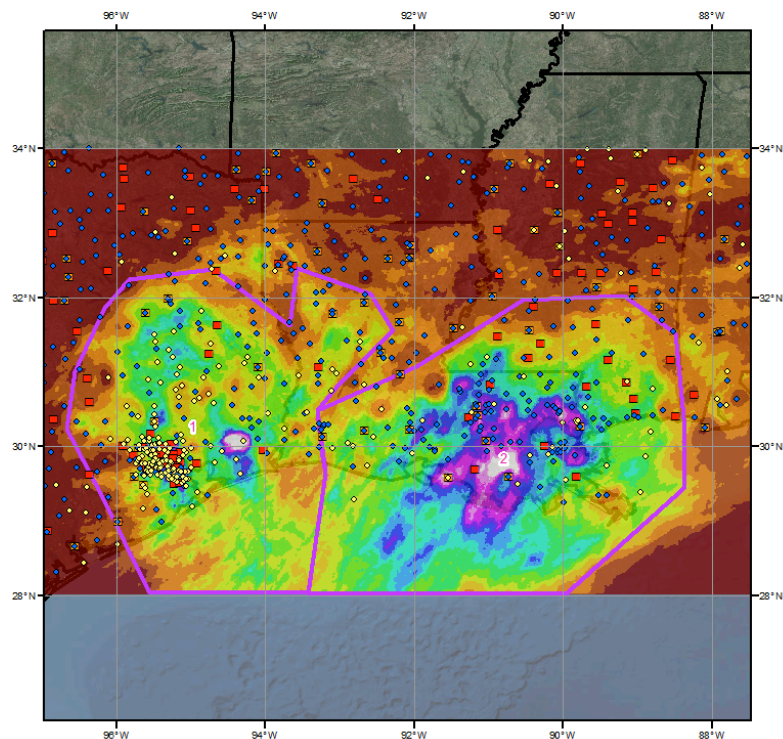
**Gauges**

- Daily
- Hourly
- Hourly Est. Pseudo
- Hourly Pseudo
- Supplemental

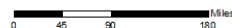
**Precipitation (inches)**

0.02 - 2.00	12.01 - 14.00	24.01 - 26.00	36.01 - 38.00	48.01 - 50.00
2.01 - 4.00	14.01 - 16.00	26.01 - 28.00	38.01 - 40.00	50.01 - 52.00
4.01 - 6.00	16.01 - 18.00	28.01 - 30.00	40.01 - 42.00	52.01 - 54.00
6.01 - 8.00	18.01 - 20.00	30.01 - 32.00	42.01 - 44.00	54.01 - 56.00
8.01 - 10.00	20.01 - 22.00	32.01 - 34.00	44.01 - 46.00	56.01 - 58.00
10.01 - 12.00	22.01 - 24.00	34.01 - 36.00	46.01 - 48.00	



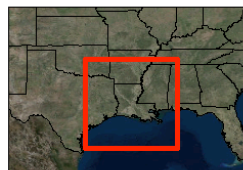
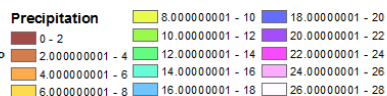


**Total Storm (144-hours) Precipitation (inches)**  
**June 5 (1200 UTC) - June 11 (11 UTC), 2001**  
**SPAS #1464 TS Allison**

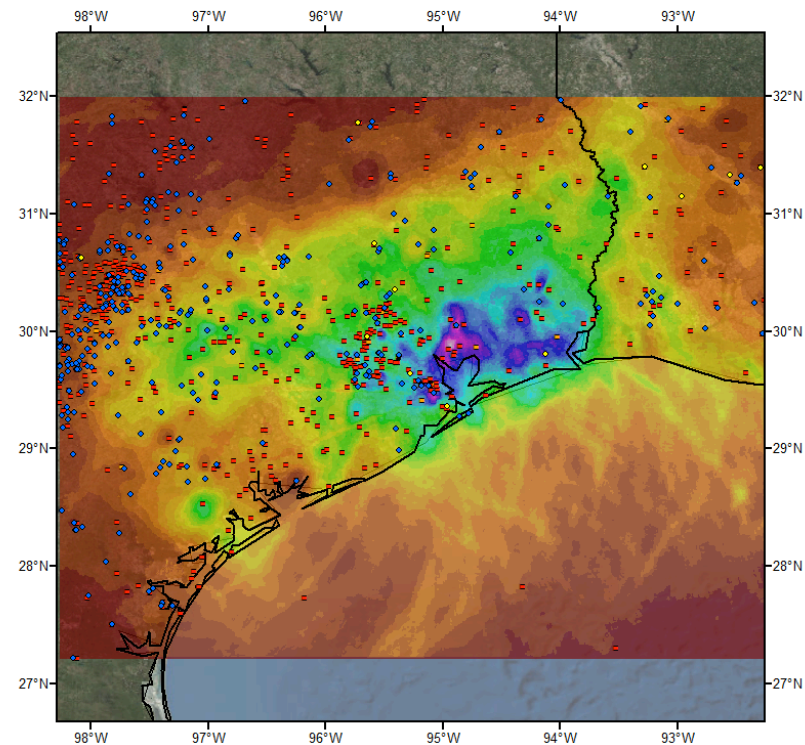


#### Gauges

- Daily
- Hourly
- Hourly Pseudo
- Supplemental



2/11/2015

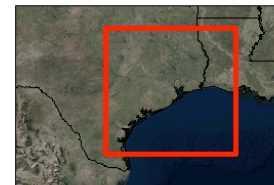
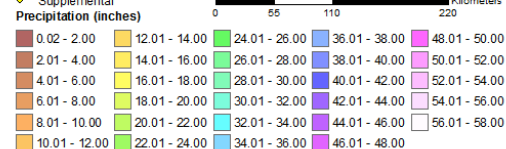


**Total Storm (156-hr) Precipitation (inches)**  
**8/25/2017 0700 UTC - 8/31/2017 1800 UTC**  
**SPAS-NEXRAD 1667 (Prelim)**



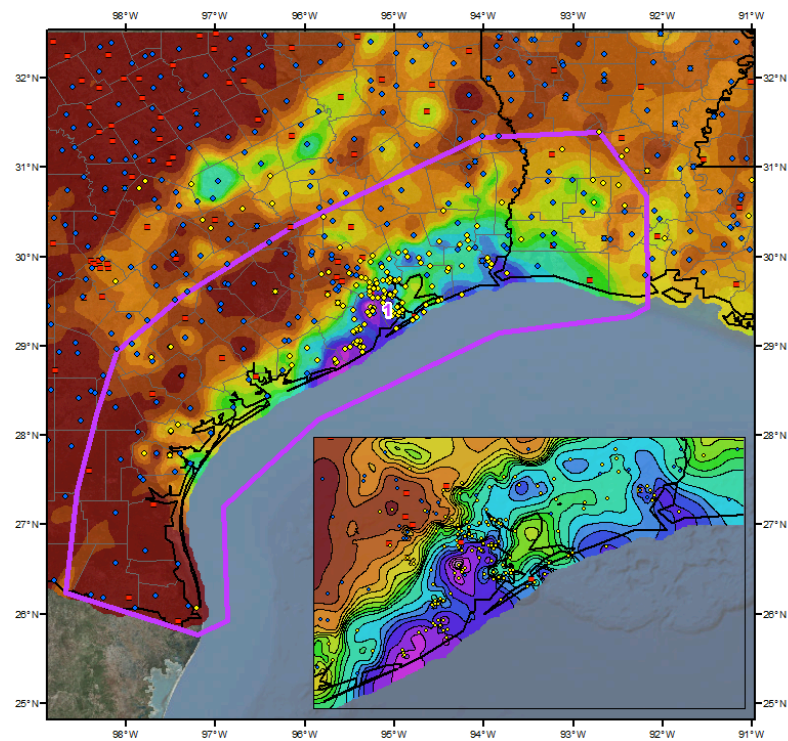
#### Gauges

- Daily
- Hourly
- Hourly Est. Pseudo
- Hourly Pseudo
- Supplemental



9/11/2017



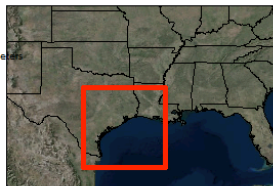
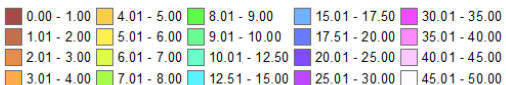


**Total Storm (120-hr) Precipitation (inches)**  
**07/23/1979 0700 UTC - 07/28/1979 0600 UTC**  
**SPAS- #1463**

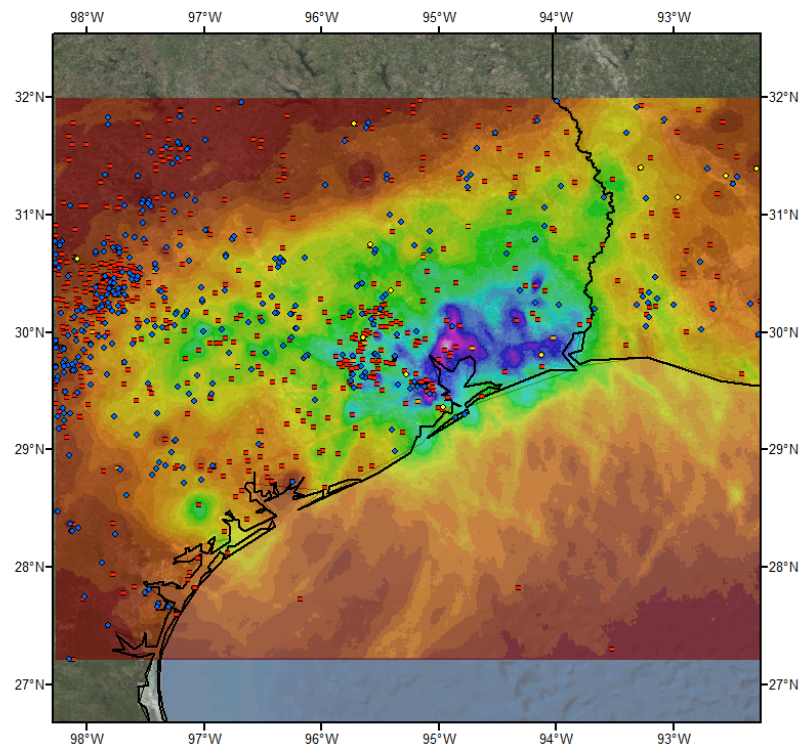
**Gauges**

- ◆ Daily
- Hourly
- Hourly Est. Pseudo
- Hourly Pseudo
- ◆ Supplemental

**Precipitation (inches)**



2/10/2015

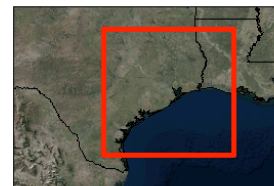
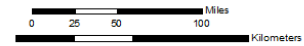
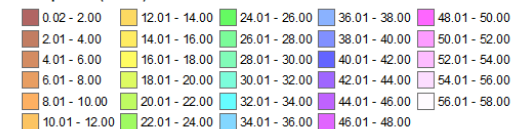


**Total Storm (156-hr) Precipitation (inches)**  
**8/25/2017 0700 UTC - 8/31/2017 1800 UTC**  
**SPAS-NEXRAD 1667 (Prelim)**

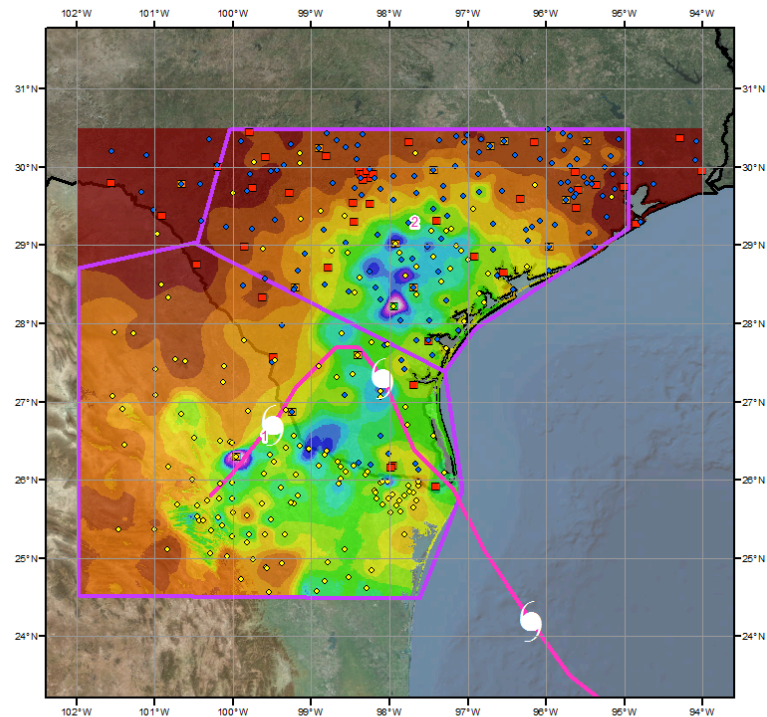
**Gauges**

- ◆ Daily
- Hourly
- Hourly Est. Pseudo
- Hourly Pseudo
- ◆ Supplemental

**Precipitation (inches)**



9/11/2017

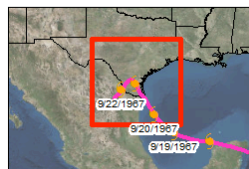
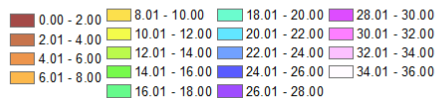


**Total Storm (144-hours) Precipitation (inches)**  
**September 19-24, 1967**  
**SPAS 1601 Sombrettillo, N.L., Mexico (SW 3-24)**

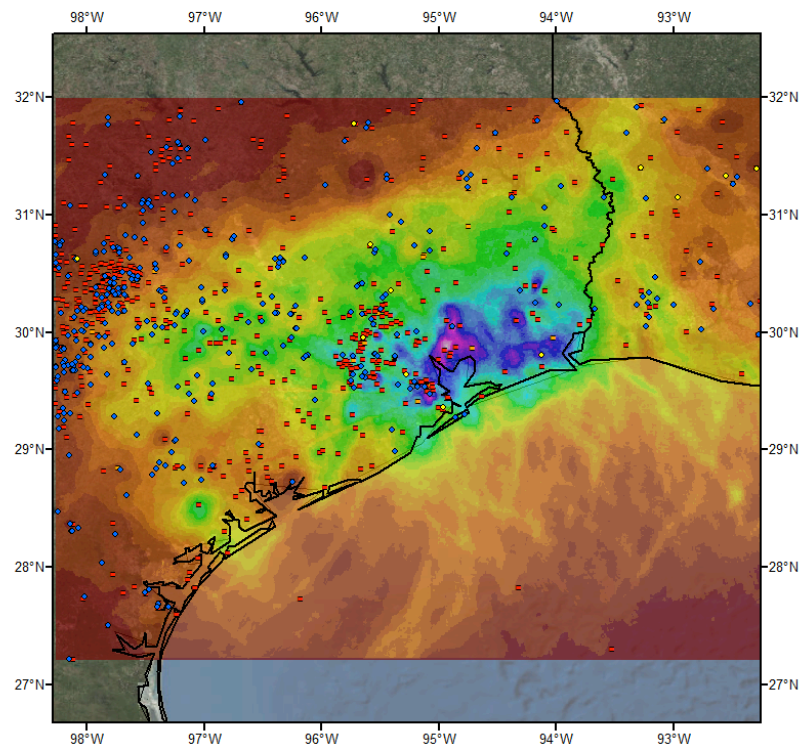
**Gauges**  
 ◆ Daily  
 ■ Hourly  
 ■ Hourly Estimated Pseudo  
 ■ Hourly Pseudo  
 ◆ Supplemental



**Precipitation (inches)**

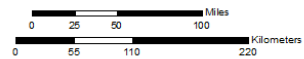


4/19/2016

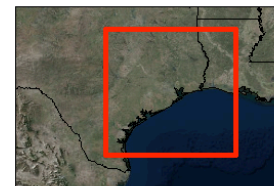
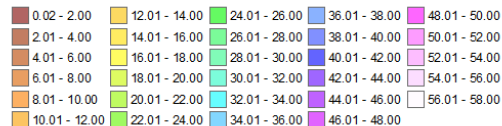


**Total Storm (156-hr) Precipitation (inches)**  
**8/25/2017 0700 UTC - 8/31/2017 1800 UTC**  
**SPAS-NEXRAD 1667 (Prelim)**

**Gauges**  
 ◆ Daily  
 ■ Hourly  
 ■ Hourly Est. Pseudo  
 ■ Hourly Pseudo  
 ◆ Supplemental



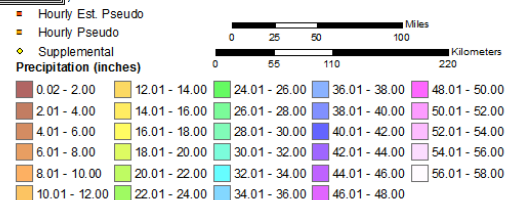
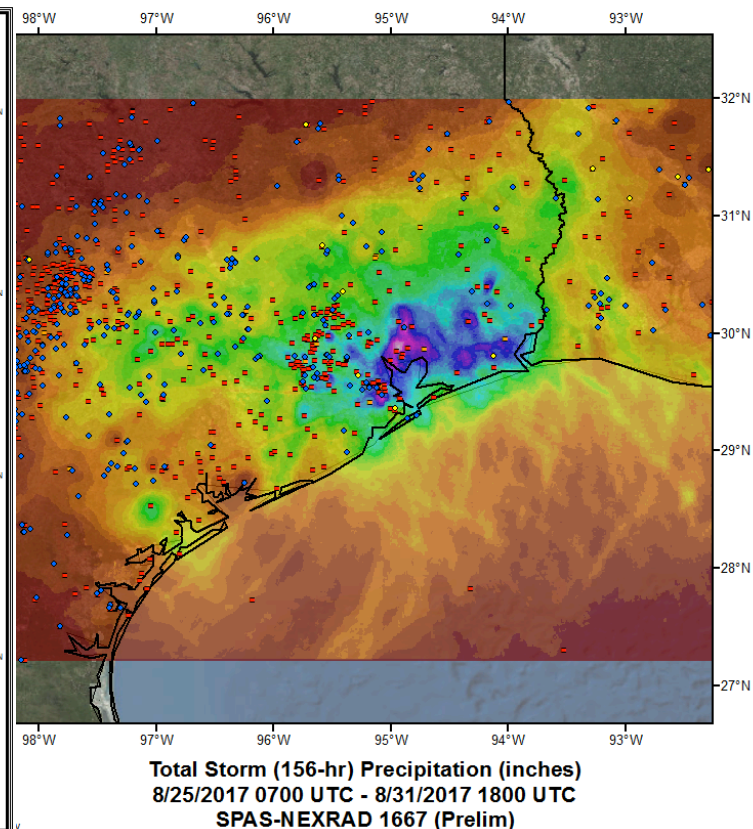
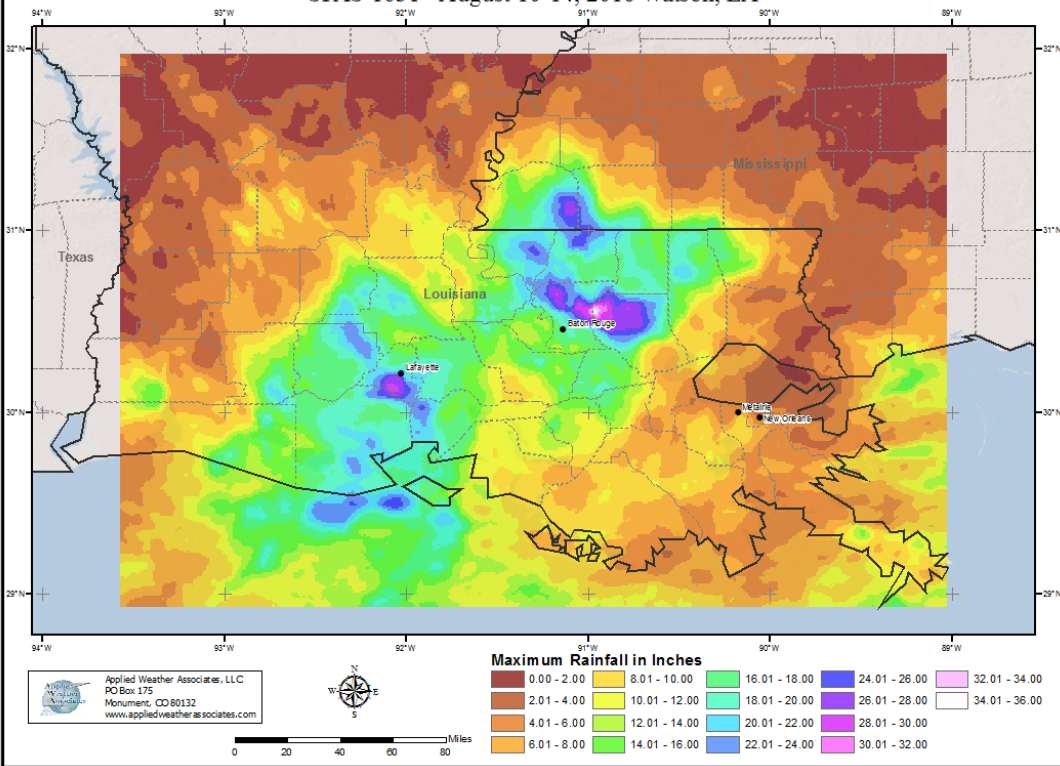
**Precipitation (inches)**



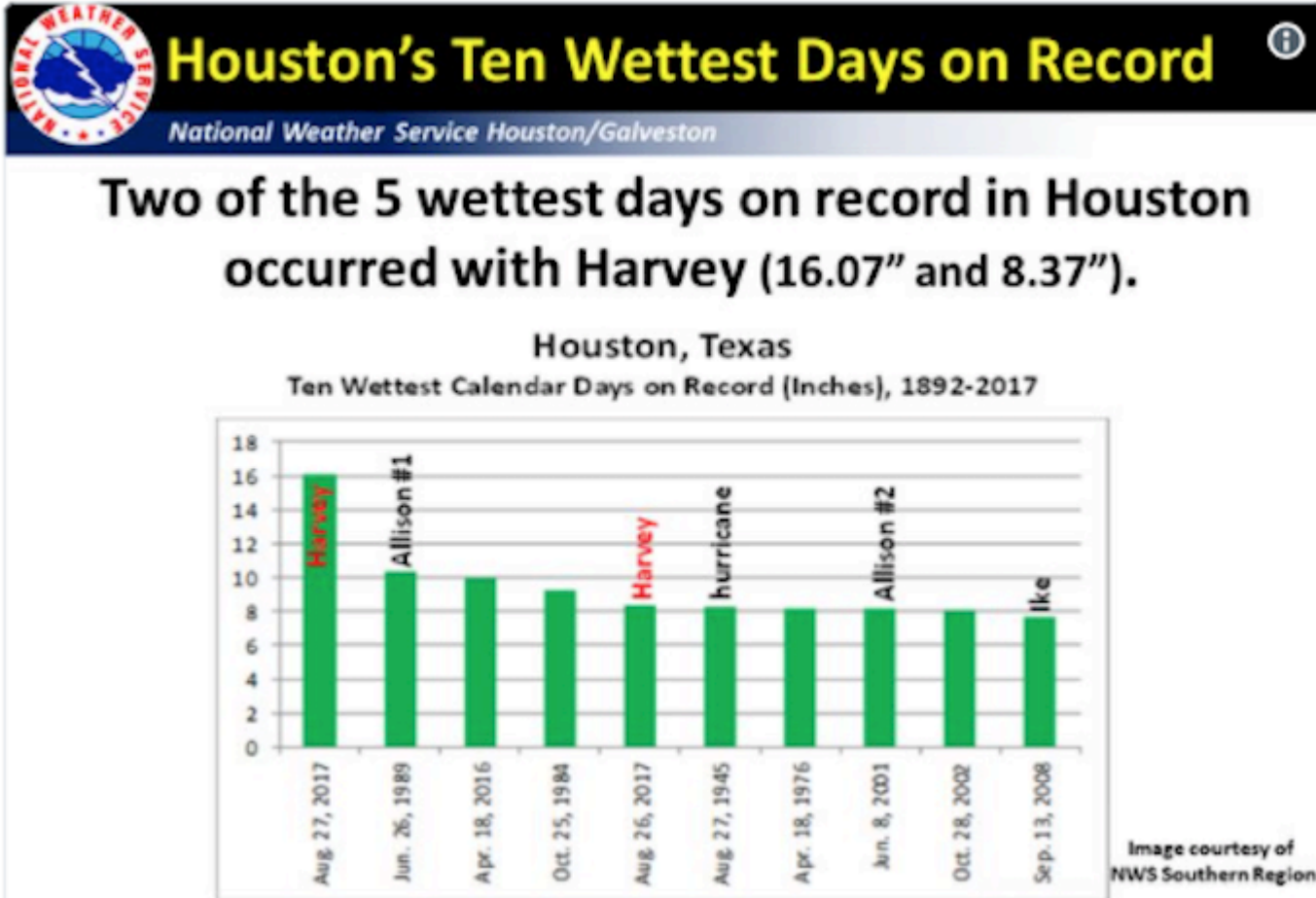
9/11/2017



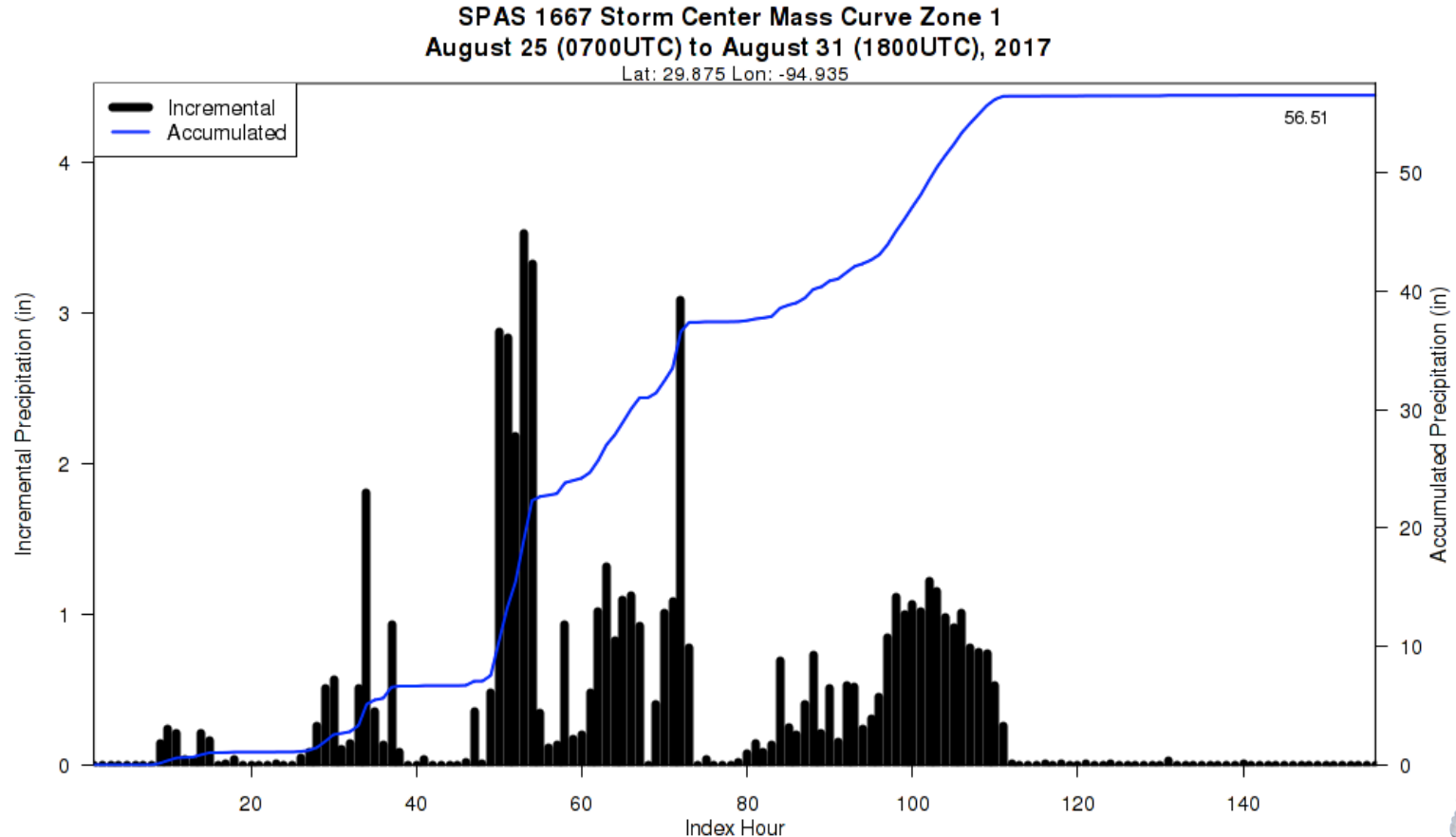
# Total Storm Rainfall SPAS 1631 - August 10-14, 2016 Watson, LA



# Daily Rainfall At Houston



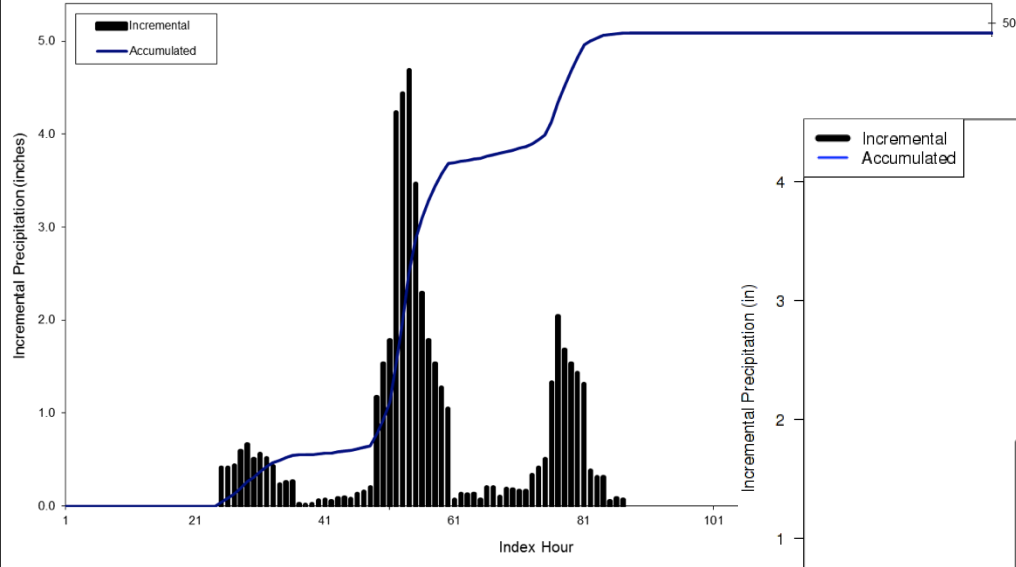
# Harvey Preliminary Storm Center Mass Curve



# Mass Curve Comparisons 1978 vs Harvey

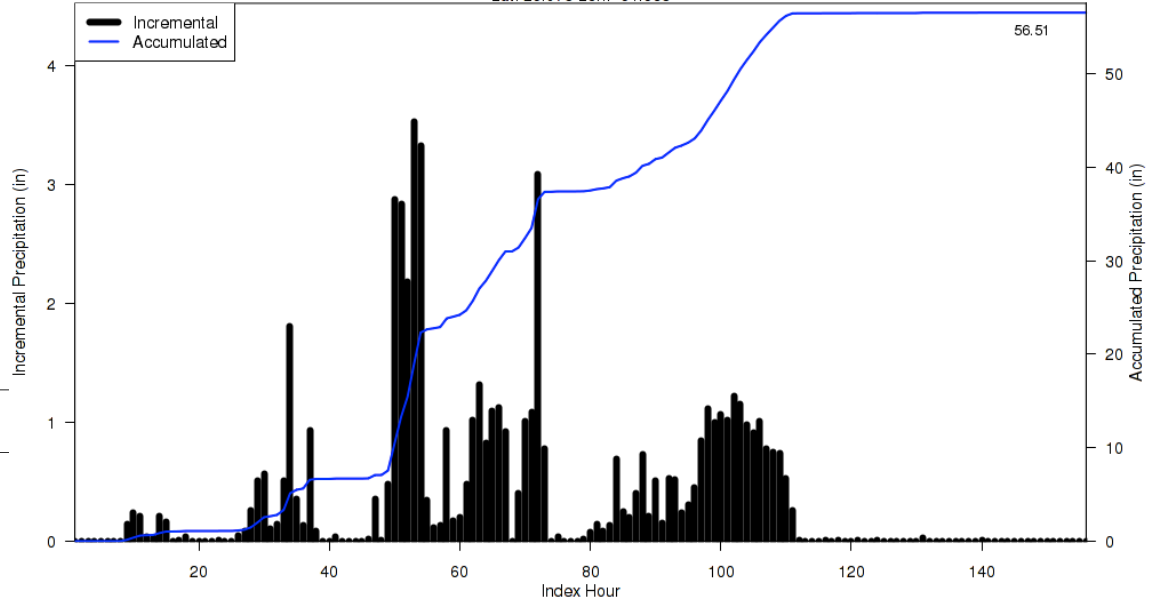
SPAS 1600 Storm Center Mass Curve: Zone 1  
July 31 (0600 UTC) - August 6 (0500 UTC), 1978

Lat: 29.8875 Lon: -99.3208



SPAS 1667 Storm Center Mass Curve Zone 1  
August 25 (0700UTC) to August 31 (1800UTC), 2017

Lat: 29.875 Lon: -94.935



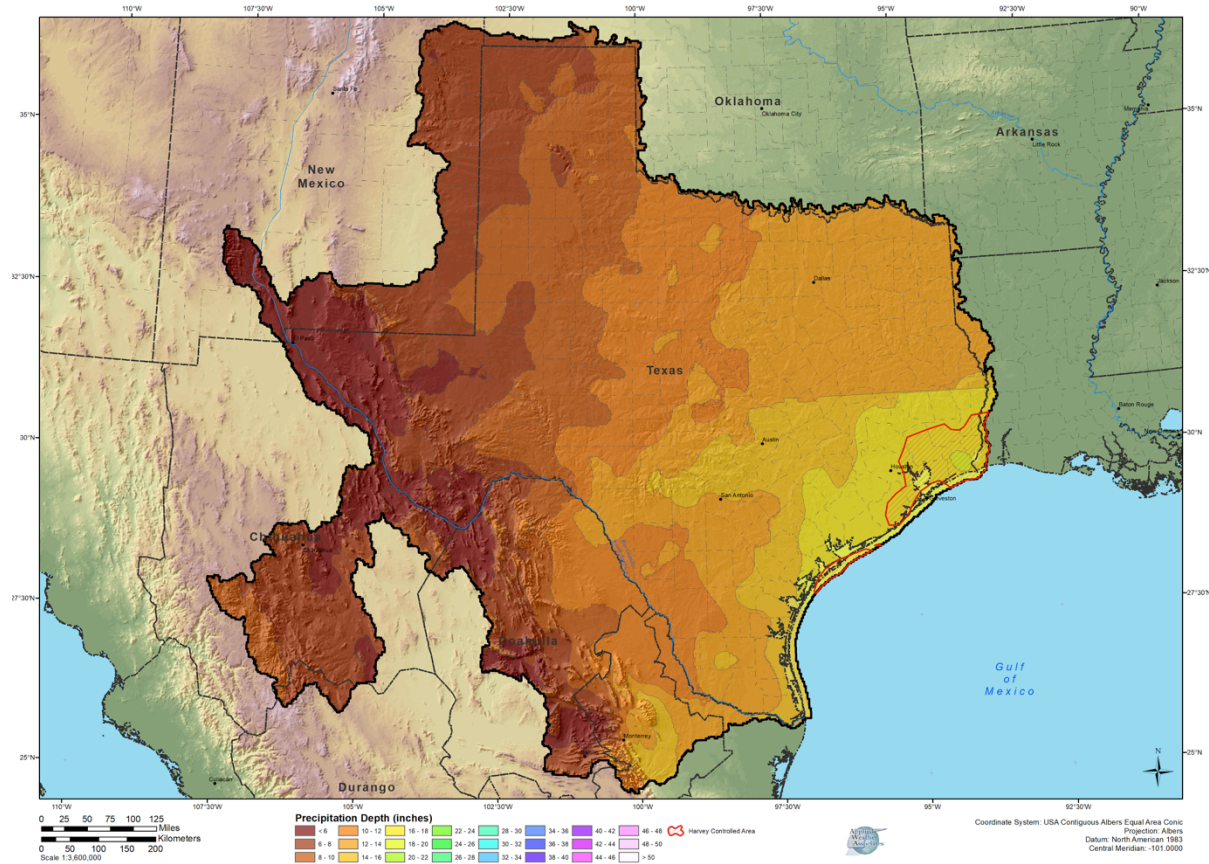
# Preliminary Harvey – DAD Table

SPAS Storm 1667 - August 25 (0700 UTC) - August 31 (1800 UTC), 2017 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
Area (mi <sup>2</sup> )	Duration (hours)									
	1	6	12	18	24	36	48	72	96	Total
0.4	5.45	19.32	23.34	28.33	32.17	35.54	40.47	49.86	55.41	56.47
1.0	5.38	19.19	23.16	28.11	31.91	35.30	40.21	49.47	54.92	55.99
10.0	5.17	18.87	22.54	27.52	31.25	34.67	39.57	47.98	53.26	54.29
25.0	5.06	18.65	21.88	26.64	30.50	33.34	38.40	46.71	51.85	52.90
50.0	4.91	18.26	21.30	25.82	30.01	31.74	37.32	45.28	50.29	51.44
100.0	4.74	17.65	20.51	24.95	29.33	31.14	36.28	44.00	48.66	49.83
150.0	4.59	17.13	19.88	24.35	28.71	30.51	35.50	43.17	47.64	48.82
200.0	4.45	16.67	19.35	23.76	28.09	29.95	34.88	42.51	46.91	48.11
300.0	4.18	15.90	18.47	22.87	26.99	28.97	33.71	41.56	45.71	46.96
400.0	3.93	15.22	17.75	22.16	26.17	28.17	32.76	40.74	44.88	46.12
500.0	3.71	14.62	17.17	21.47	25.53	27.52	32.01	40.11	44.13	45.48
1000.0	2.99	12.21	15.20	19.09	22.68	25.11	29.36	37.56	41.67	43.29
2000.0	2.36	9.46	12.85	16.31	19.66	22.69	26.80	34.39	39.13	40.94
3500.0	1.85	7.58	11.03	14.23	17.41	20.76	24.79	31.35	36.49	38.41
5000.0	1.57	6.58	9.99	12.96	15.99	19.44	23.54	29.40	34.51	36.34
7500.0	1.29	5.58	8.83	11.66	14.39	17.97	21.90	26.99	31.83	33.88
10000.0	1.12	4.94	8.06	10.59	13.30	16.86	20.81	25.35	29.89	31.84
15000.0	0.89	4.17	6.95	9.24	11.55	15.18	18.66	22.84	26.83	28.93
20000.0	0.71	3.64	6.10	8.14	10.38	13.77	17.04	21.03	24.75	26.68
35000.0	0.52	2.71	4.65	6.27	7.83	10.67	13.40	17.10	20.12	22.11
50000.0	0.39	2.11	3.60	4.93	6.27	8.83	11.06	14.24	16.69	18.79
75000.0	0.29	1.53	2.69	3.68	4.62	6.61	8.37	11.33	13.32	15.06
100000.0	0.22	1.21	2.20	3.00	3.75	5.30	6.71	9.08	10.71	12.11
120162.0	0.18	1.05	1.91	2.59	3.22	4.59	5.83	7.88	9.31	10.53



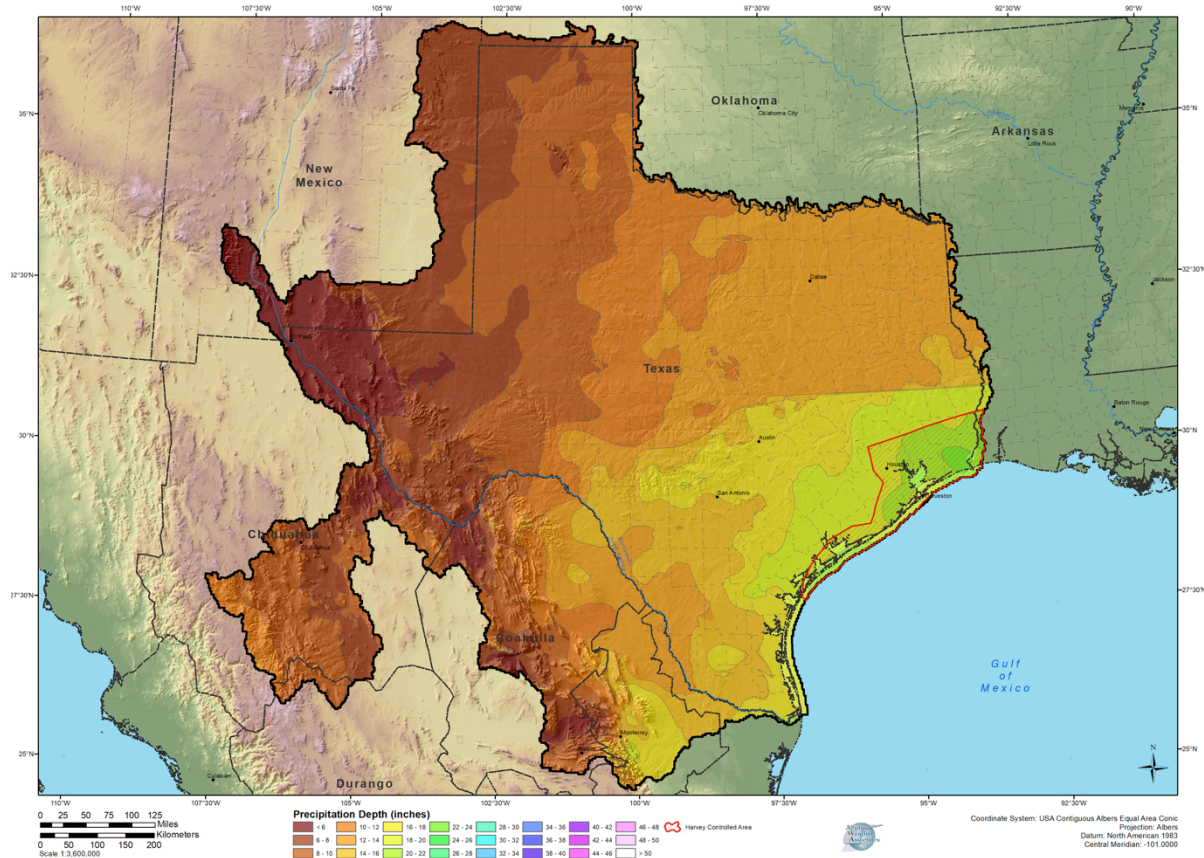
# Where Does Harvey Control PMP?

**48-hour Probable Maximum Precipitation - Tropical Storm - 20,000 mi<sup>2</sup>**  
Impact on PMP Due to Hurricane Harvey (SPAS 1667) Preliminary Analysis



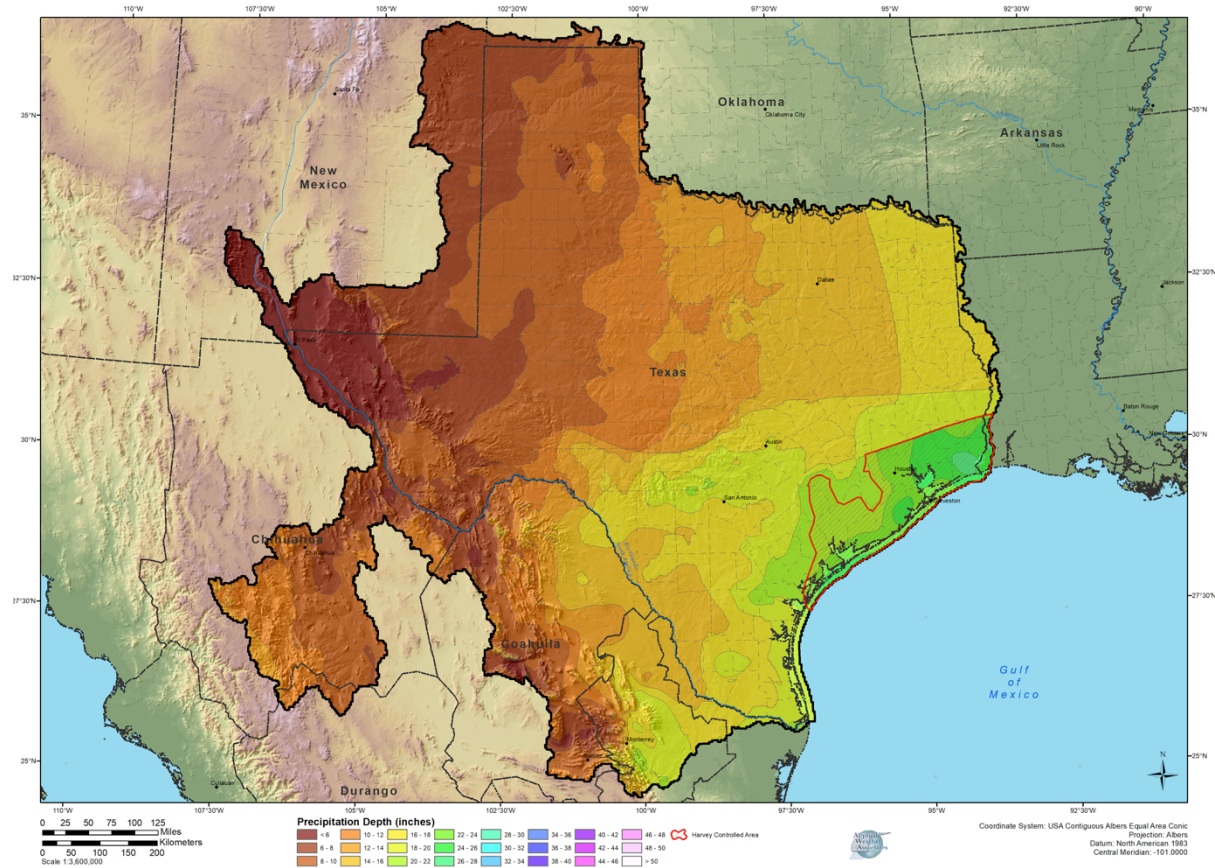
# Where Does Harvey Control PMP?

**72-hour Probable Maximum Precipitation - Tropical Storm - 20,000 mi<sup>2</sup>**  
Impact on PMP Due to Hurricane Harvey (SPAS 1667) Preliminary Analysis



# Where Does Harvey Control PMP?

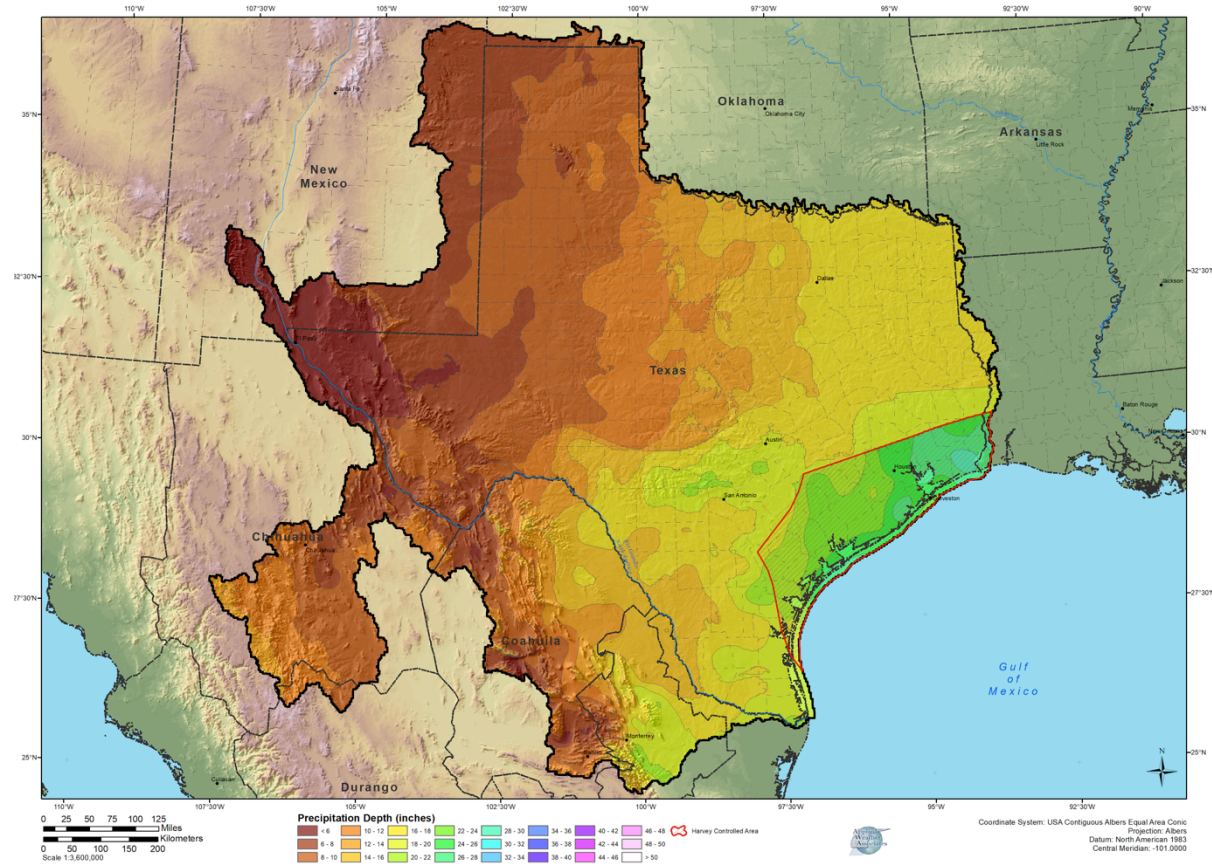
**96-hour Probable Maximum Precipitation - Tropical Storm - 20,000 mi<sup>2</sup>**  
Impact on PMP Due to Hurricane Harvey (SPAS 1667) Preliminary Analysis





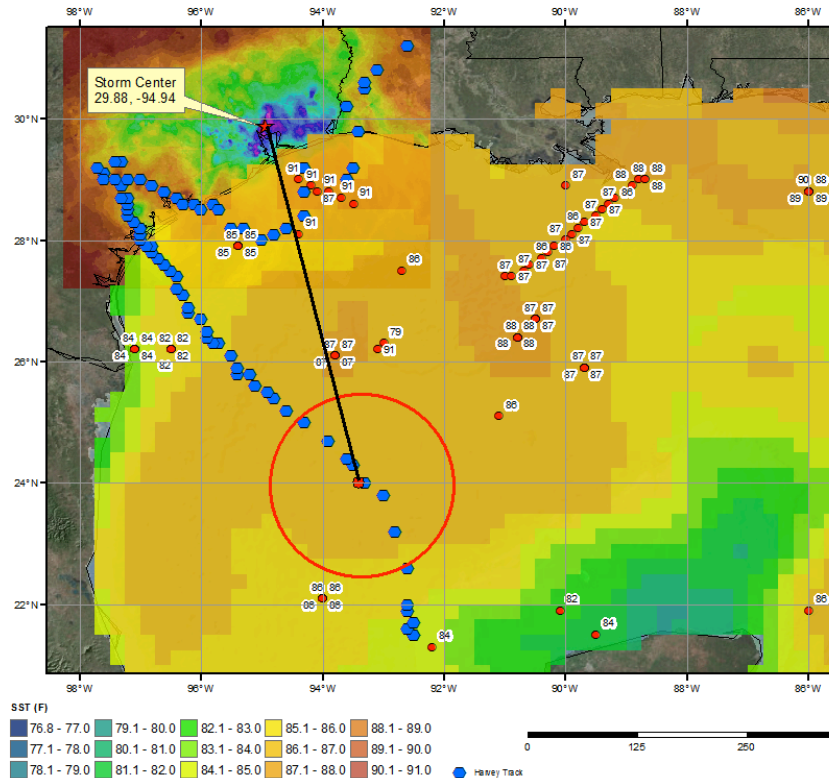
# Where Does Harvey Control PMP?

**120-hour Probable Maximum Precipitation - Tropical Storm - 20,000 mi<sup>2</sup>**  
Impact on PMP Due to Preliminary Hurricane Harvey (SPAS 1667) Analysis

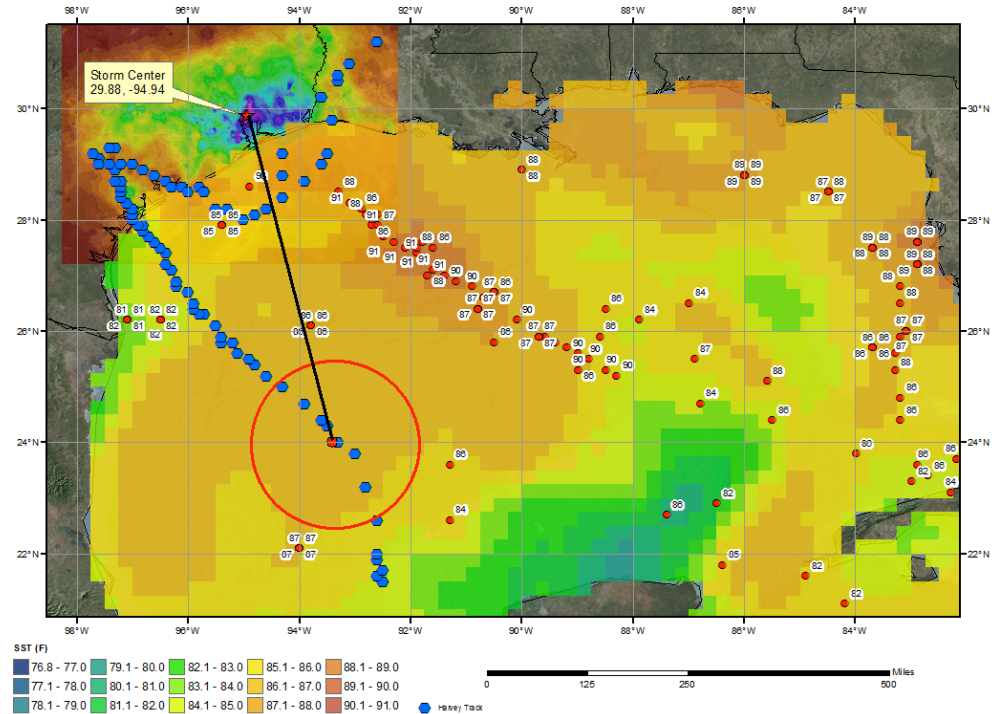


# Harvey In-Place Maximization

SPAS 1667 Harvey, TX Storm Analysis  
August 24, 2017

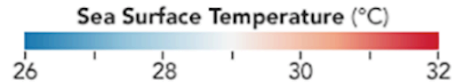
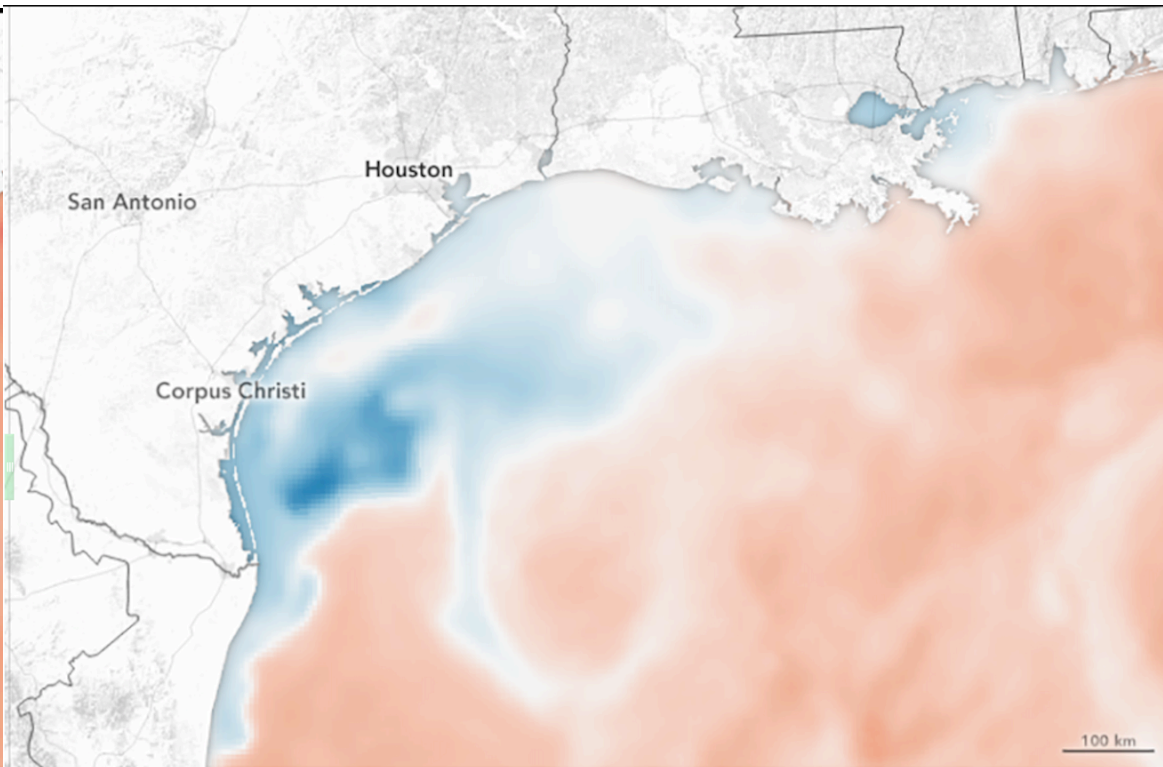
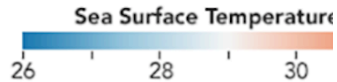
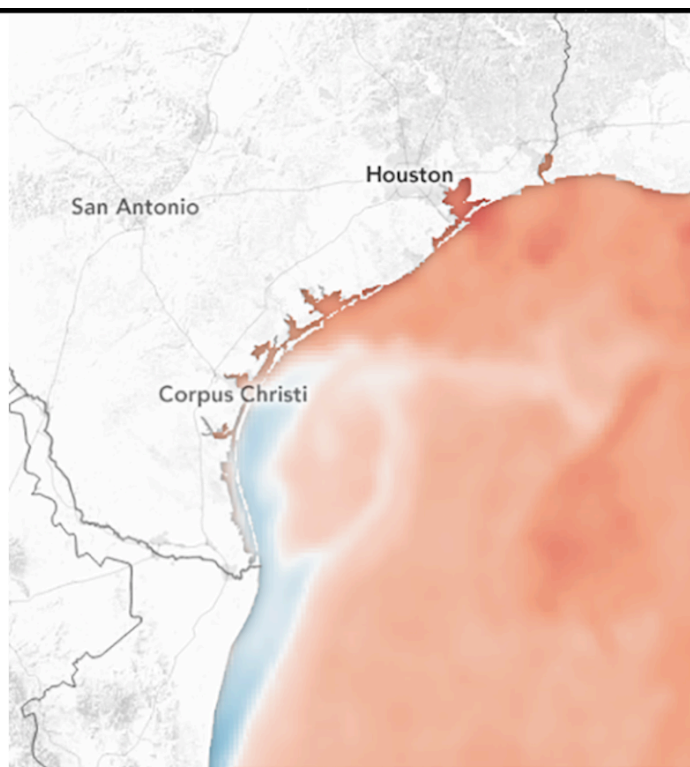


SPAS 1667 Harvey, TX Storm Analysis  
August 25, 2017





# Sea Surface Temperatures During and After



# Storm Maximization Spreadsheet

<b>Storm Name:</b>	<b>SPAS 1667 - Hurricane Harvey</b>	<b>Storm Adjustment for Grid Points XX</b>			
<b>Storm Date:</b>	<b>August 24-29, 2017</b>				
<b>AWA Analysis Date:</b>	<b>9/11/17</b>				

<b>Temporal Transposition Date</b>	<b>15-Aug</b>								
	<b>Lat</b>	<b>Long</b>			<b>Moisture Inflow Direction</b>	<b>SSE @ 415</b>	<b>miles</b>		
<b>Storm Center Location</b>	<b>29.88 N</b>	<b>94.94 W</b>			<b>Basin Average Elevation</b>	<b>NA</b>	<b>feet</b>		
<b>Storm Rep SST Location</b>	<b>24.0 N</b>	<b>93.4 W</b>			<b>Storm Center Elevation</b>	<b>40</b>	<b>feet</b>		
<b>Transposition SST Location</b>	<b>NA</b>	<b>NA</b>			<b>Storm Analysis Duration</b>	<b>24</b>	<b>hours</b>		
<b>Basin Location</b>	<b>*</b>	<b>*</b>			<b>Effective Barrier Height</b>	<b>NA</b>	<b>feet</b>		

The storm representative SST is	<b>86.5 F</b>	with total precipitable water above sea level of				<b>4.77</b>	inches.
The in-place maximum SST is	<b>87.0 F</b>	with total precipitable water above sea level of				<b>4.86</b>	inches.
The transpositioned maximum SST is	<b>NA</b>	with total precipitable water above sea level of				<b>#VALUE!</b>	inches.
The in-place storm elevation is	<b>40</b>	feet which subtracts	<b>0.02</b>	inches of precipitable water at		<b>86.5 F</b>	
The in-place storm elevation is	<b>40</b>	feet which subtracts	<b>0.02</b>	inches of precipitable water at		<b>87.0 F</b>	
The transposition storm elevation at	<b>NA</b>	feet which subtracts	<b>#VALUE!</b>	inches of precipitable water at		<b>NA</b>	
The moisture inflow barrier height is	<b>NA</b>	feet which subtracts	<b>#VALUE!</b>	inches of precipitable water at		<b>NA</b>	

The in-place maximization factor is	<b>1.02</b>
The transposition factor is	<b>#VALUE!</b>
The elevation/barrier adjustment factor is	<b>#VALUE!</b>
The total adjustment factor is	<b>#VALUE!</b>

Notes: Storm representative SST value was based on 24 hour SST values on August 23-25, 2017.

# Harvey Comparison to Previous Large Storms

Duration: 48 h				Duration: 72 h				Duration: 120 h			
Area: 1000 sq mi				Area: 1000 sq mi				Area: 1000 sq mi			
Event	Average (in)	Amount (mrd)	% over previous record	Event	Average (in)	Amount (mrd)	% over previous record	Event	Average (in)	Amount (mrd)	% over previous record
LA Aug 1940	29.53	1.3	-0.6%	Harvey 2017	37.56	1.7	16%	Harvey 2017	43.29	2.1	33%
Harvey 2017	29.36	1.3	Harvey rel to HMR 51	LA Aug 1940	32.51	1.5	Harvey rel to HMR 51	LA Aug 1940	32.64	1.5	
TX Jun 1899	27.63	1.3	-22%	TX Jun 1899	31.10	1.4	-9%	TX Jun 1899	31.91	1.5	
Danny 1997	25.69	1.2	Harvey rel to AWA zone	Danny 1997	27.10	1.2	Harvey rel to AWA zone	Claudette 1979	27.78	1.3	
Claudette 1979	23.97	1.1	-17%	Alice 1954	26.93	1.2	-9%	Beulah 1967	27.20	1.2	
Area: 5000 sq mi				Area: 5000 sq mi				Area: 5000 sq mi			
Event	Average (in)	Amount (mrd)	% over previous record	Event	Average (in)	Amount (mrd)	% over previous record	Event	Average (in)	Amount (mrd)	% over previous record
Harvey 2017	23.54	5.5	11%	Harvey 2017	29.40	7.1	22%	Harvey 2017	36.34	9.0	42%
LA Aug 1940	21.15	4.8	Harvey rel to HMR 51	TX Jun 1899	24.19	5.5	Harvey rel to HMR 51	TX Jun 1899	25.60	5.8	
TX Jun 1899	20.01	4.5	-12%	LA Aug 1940	23.63	5.4	-4%	LA Aug 1940	23.93	5.4	
TX Oct 1994	18.60	4.2	Harvey rel to AWA zone	Beulah 1967	20.70	4.7	Harvey rel to AWA zone	Beulah 1967	22.40	5.1	
Georges 1998	18.33	4.2	-11%	TX Oct 1994	20.15	4.6	-1%	TX Oct 1994	20.86	4.7	
Area: 10000 sq mi				Area: 10000 sq mi				Area: 10000 sq mi			
Event	Average (in)	Amount (mrd)	% over previous record	Event	Average (in)	Amount (mrd)	% over previous record	Event	Average (in)	Amount (mrd)	% over previous record
Harvey 2017	20.81	9.7	25%	Harvey 2017	25.35	12.2	27%	Harvey 2017	31.84	15.7	49%
Georges 1998	16.62	7.5	Harvey rel to HMR 51	TX Jun 1899	19.97	9.1	Harvey rel to HMR 51	TX Jun 1899	21.39	9.7	
LA Aug 1940	16.16	7.3	-8%	Beulah 1967	18.50	8.4	-4%	Beulah 1967	20.50	9.3	
TX Jun 1899	16.02	7.3	Harvey rel to AWA zone	LA Aug 1940	17.94	8.1	Harvey rel to AWA zone	LA Aug 1940	18.37	8.3	
TX Oct 1994	16.00	7.3	-5%	TX Oct 1994	17.45	7.9	5%	TX Oct 1994	18.06	8.2	
Area: 20000 sq mi				Area: 20000 sq mi				Area: 20000 sq mi			
Event	Average (in)	Amount (mrd)	% over previous record	Event	Average (in)	Amount (mrd)	% over previous record	Event	Average (in)	Amount (mrd)	% over previous record
Harvey 2017	17.04	16.0	17%	Harvey 2017	21.03	19.7	29%	Harvey 2017	26.68	25.6	43%
Georges 1998	14.58	13.2	Harvey rel to HMR 51	Beulah 1967	16.30	14.8	Harvey rel to HMR 51	Beulah 1967	18.70	17.0	
Beulah 1967	13.00	11.8	-5%	TX Jun 1899	15.29	13.9	-4%	TX Jun 1899	17.02	15.4	
TX Oct 1994	12.46	11.3	Harvey rel to AWA zone	Georges 1998	14.58	13.2	Harvey rel to AWA zone	Georges 1998	15.71	14.3	
Floyd 1999	12.05	10.9	-5%	TX Oct 1994	13.92	12.6	13%	NC Sep 2010	14.83	13.4	

# Harvey Comparison to Previous PMP

	Average Tropical PMP (post-Harvey)	Average Tropical PMP (pre-Harvey)	Average % Increase	Average General PMP (pre-Harvey)	Average % Increase over General PMP	Average HMR 51 PMP	Average % Increase from HMR 51
5,000-sqmi 48-hour	-	-	-	-	No Increase	-	No Increase
5,000-sqmi 72-hour	29.2"	27.4"	6.6%	36.0"	No Increase	31.1"	No Increase
5,000-sqmi 96-hour	30.7"	N/A	-	N/A	-	N/A	No Increase
5,000-sqmi 120-hour	32.3"	N/A	-	N/A	-	N/A	No Increase
10,000-sqmi 48-hour	21.6"	21.1"	2.5%	25.0"	No Increase	22.9"	No Increase
10,000-sqmi 72-hour	25.0"	23.4"	7.1%	29.6"	No Increase	26.8"	No Increase
10,000-sqmi 96-hour	26.6"	23.6"	12.5%	28.2"	No Increase	N/A	No Increase
10,000-sqmi 120-hour	28.3"	23.8"	18.9%	28.4"	No Increase	N/A	No Increase
20,000-sqmi 48-hour	17.1"	16.2"	5.4%	20.5"	No Increase	22.8"	No Increase
20,000-sqmi 72-hour	20.4"	18.4"	10.9%	22.3"	No Increase	26.8"	No Increase
20,000-sqmi 96-hour	23.2"	20.6"	12.8%	23.1"	<b>0.6%</b>	N/A	No Increase
20,000-sqmi 120-hour	23.8"	20.8"	14.8%	22.8"	<b>4.4%</b>	N/A	No Increase

# Harvey on the World Curve Table

