

A Summary of Meteorological Parameters During Space Shuttle Pad Exposure Periods

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During the 113 missions of the Space Transportation System (STS), the Space Shuttle fleet has been exposed to the elements on the launch pad for a total of 4195 days. The Natural Environments Branch at Marshall Space Flight Center archives atmospheric environments to which the Space Shuttle vehicles are exposed. This paper provides a summary of the historical record of the meteorological conditions encountered by the Space Shuttle fleet during the pad exposure period. Sources of the surface parameters, including temperature, dew point temperature, relative humidity, wind speed, wind direction, sea level pressure and precipitation are presented. Data is provided from the first launch of the STS in 1981 through the launch of STS-107 in 2003.

Nomenclature

\bar{H}	= scale height
$P_{\Delta Z}$	= barometric pressure at height ΔZ above sea level
SLP	= sea level pressure
ΔZ	= height above sea level

I. Introduction

FROM the time the Space Shuttle stack is rolled out from the Vehicle Assembly Building (VAB) to the launch pad, it is exposed to the natural environment at Kennedy Space Center (KSC). From the first mission, STS-1 which launched on April 12, 1981, thru STS-107, which launched on January 16, 2003, the Space Shuttle vehicles have been exposed on the launch pad for a total of 4195 days.

As part of the Columbia Accident Investigation, the Natural Environments Branch at Marshall Space Flight Center (MSFC) was tasked to document the meteorological conditions to which all the Space Shuttle vehicles were exposed while on the launch pad. The intent of this paper is to give a description of the meteorological data that has been recorded while the Space Shuttle vehicle was on the launch pad. A National Aeronautics and Space Administration (NASA) Technical Memorandum is planned to be released in 2005 that contains a full set of pad exposure period meteorological data for all of the Space Shuttle missions.

II. MSFC Natural Environments Branch

The Natural Environments Branch is part of the Spacecraft & Vehicle Systems Department at Marshall Space Flight Center. The mission of the group is to provide information on naturally occurring space environments, terrestrial environments, and planetary atmospheric environments to customers at MSFC and other NASA centers. The Natural Environment Branch's Terrestrial and Planetary Environments Team archives and models the terrestrial environment to support aerospace vehicle design, development, and analysis and models planetary environments to be used for aerospace vehicle engineering studies.

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The Terrestrial and Planetary Environments Team has been tasked by the Space Shuttle program to provide technical management of the natural environments area. This includes certifying new atmospheric instrumentation for use by the Space Shuttle program, archiving surface and upper atmospheric thermodynamic and wind measurements made at the Kennedy Space Center and the U.S. Air Force Eastern Range, climatological modeling, day-of-launch wind profile monitoring and verification, documentation of atmospheric environment during ascent (the final meteorological profile), and terrestrial environment requirements development.

III. Description of Data Sources

The data in this paper were collected over a period of approximately 23 years at surface observation stations and from meteorological (MET) towers at KSC.

A. Surface Observations

Hourly surfaces observations from two sites are included in the archive and used for this paper. Table 1 gives the source information, including the station call sign, Weather Bureau Army/Navy (WBAN) designation, World Meteorological Organization (WMO) designation, approximate location with respect to the Space Shuttle Launch Complex 39 (LC-39) and period of record for the archive. The location of these observation stations is shown in Figure 1.

Due to questionable hourly precipitation data from Station 12868, daily precipitation totals as measured at Station 12886 and provided by the Air Force Combat Climatology Center are presented in this document through STS-86 (September 1997). Since STS-86, precipitation has been measured near the pads with optical rain gauges.

The surface observation data were obtained near ground level. Temperature, relative humidity, pressure and precipitation are measured at approximately 1.5 m above ground level. Wind speed and direction are measured at approximately 9 m above ground level.

B. MET Tower Observations

Data from six MET towers have been archived by the MSFC Natural Environments Branch and are used in this document. Tower 393 is on the northwest side of Launch Pad 39A (LP-39A) and Tower 394 is on the southeast side. Tower 397 is on the northwest side of LP-39B and Tower 398 is on the southeast side. The location of these towers is shown in Figure 1. Each tower is approximately 0.4 km from their respective launch pad.

The wind data from Towers 393, 394, 397 and 398 were measured at 18.3 m above natural grade (ANG). The temperature, humidity and dew point from Towers 393, 394, 397 and 398 were measured at both 1.8 m ANG which is equivalent to approximately 6.4 m above mean sea level (MSL) and 18.3 m ANG. All data from Tower 313 were measured at 16 m ANG because Tower 313 is not instrumented at 18.3 m ANG.

From STS-56 (March 1993) to STS-80 (October 1996), the tower data consisted of temperature, dew point, relative humidity, wind speed and wind direction. After this time, pressure measurements were added to Towers 394 and 398 only. The pressure data were measured at approximately 6.4 m above MSL. The measured pressure values were adjusted to sea level pressure to provide a common reference level using the following equation:

$$SLP = P_{\Delta Z} \left(1 + \frac{\Delta Z}{H} \right) \quad (1)$$

Table 1. Surface observation data source descriptions.

Source	Location	Period of Record
Cape Canaveral Air Force Station (CCAFS) Call Sign: XMR WBAN Station #12868	16 km south of LC-39	12/1980 – 11/1984
Shuttle Landing Facility (SLF) Call Signs: X68, TTS & KTTS WMO Station #74794 WBAN Station #12886	8 km west of LC-39	12/1984 - Present

Where, SLP is sea level pressure, $P_{\Delta Z}$ is the measured (barometric) pressure, ΔZ is the height of the barometer above sea level in meters and \bar{H} is the scale height (8500 m). This equation is a simplified form of the hypsometric equation¹ and is accurate to within about 0.1 hPa for ΔZ less than about 120 m.

After STS-80, optical rain gauges were added to Towers 393, 394, 397 and 398. The optical rain gauges provide one-second precipitation measurements. This data is available only sporadically prior to STS-87 (October 1987).

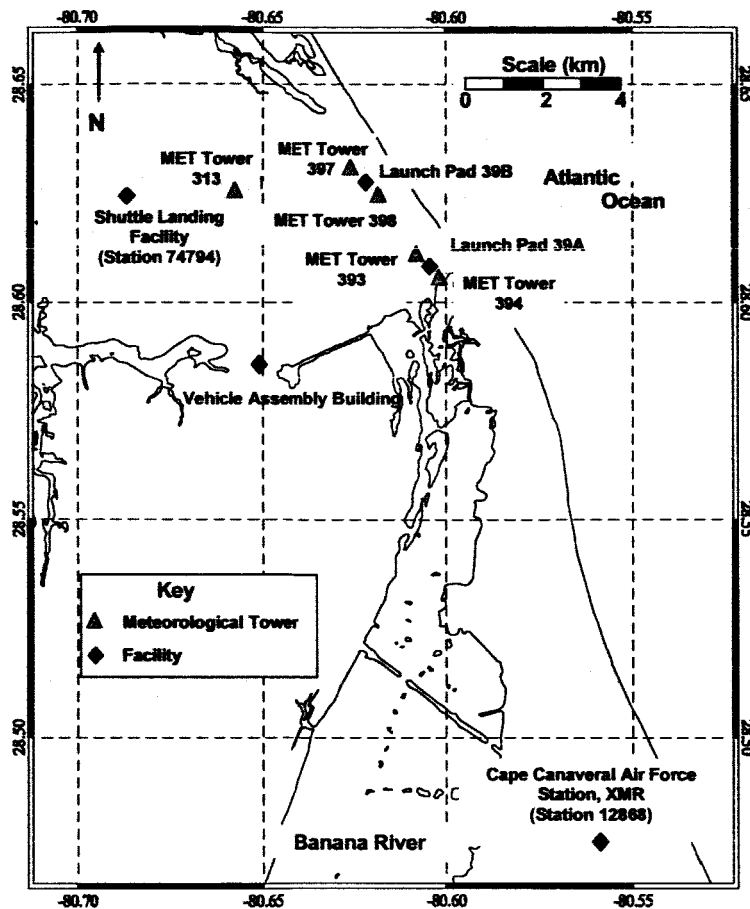


Figure 1. Kennedy Space Center meteorological observation locations.

IV. Sample Data

A. STS-113

This section presents an example of the type of data available for all Space Shuttle missions. This data is from STS-113, launched on November 23, 2002. Table 2 shows the hourly extremes of the various meteorological parameters while STS-113 was on the pad. Figures 2 through 7 show the temperature, relative humidity, wind speed, wind direction, sea level pressure, and precipitation as recorded at MET Tower 394 while STS-113 was on the pad.

Table 2. STS-113 pad exposure period hourly extremes.

Min. Temperature	6.7 °C (44 °F)
Max. Temperature	30.0 °C (86 °F)
Min. Relative Humidity	35%
Max. Relative Humidity	100%
Min. Sea Level Pressure	1004.7 hPa (29.67 in Hg)
Max. Sea Level Pressure	1028.4 hPa (30.37 in Hg)
Max. Wind Speed & Associated Wind Direction	17.5 m/s (34 kts) 269 deg.
Total Precipitation	58.7 mm (2.31 in.)

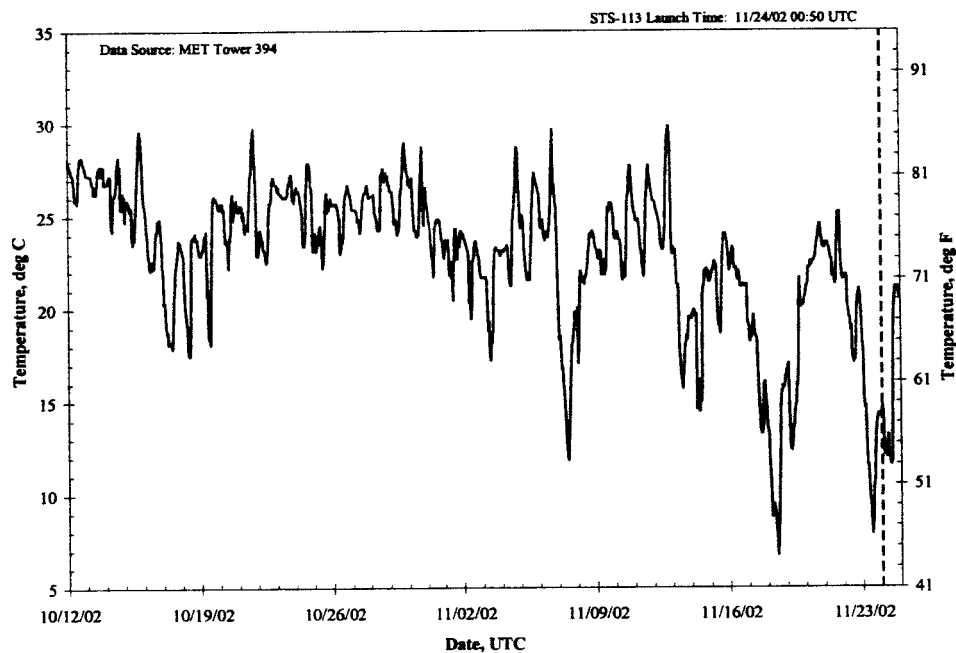


Figure 2. STS-113 Hourly temperature at 18 m (60 ft.).

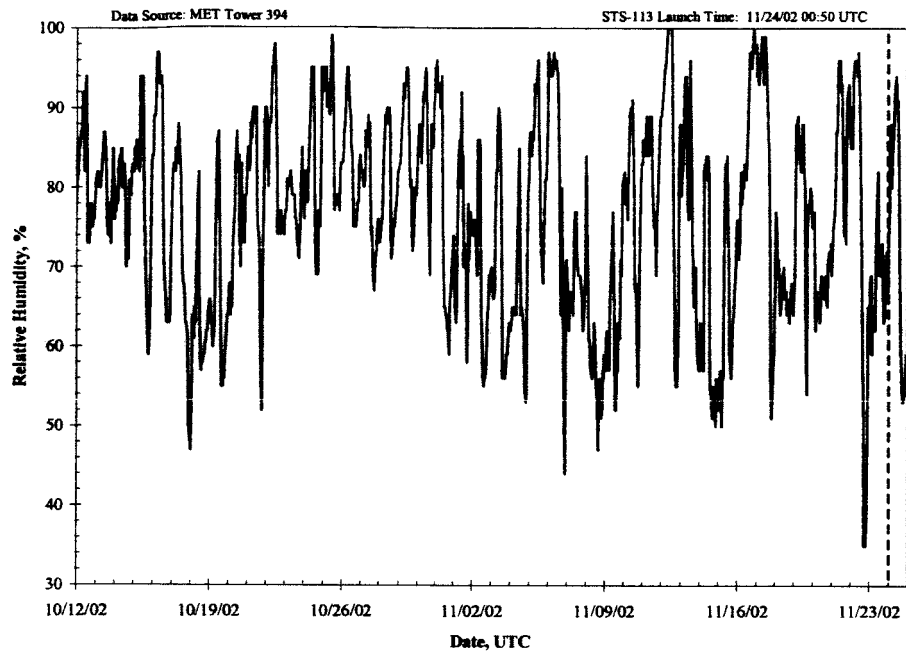


Figure 3. STS-113 Hourly relative humidity at 18 m (60 ft.).

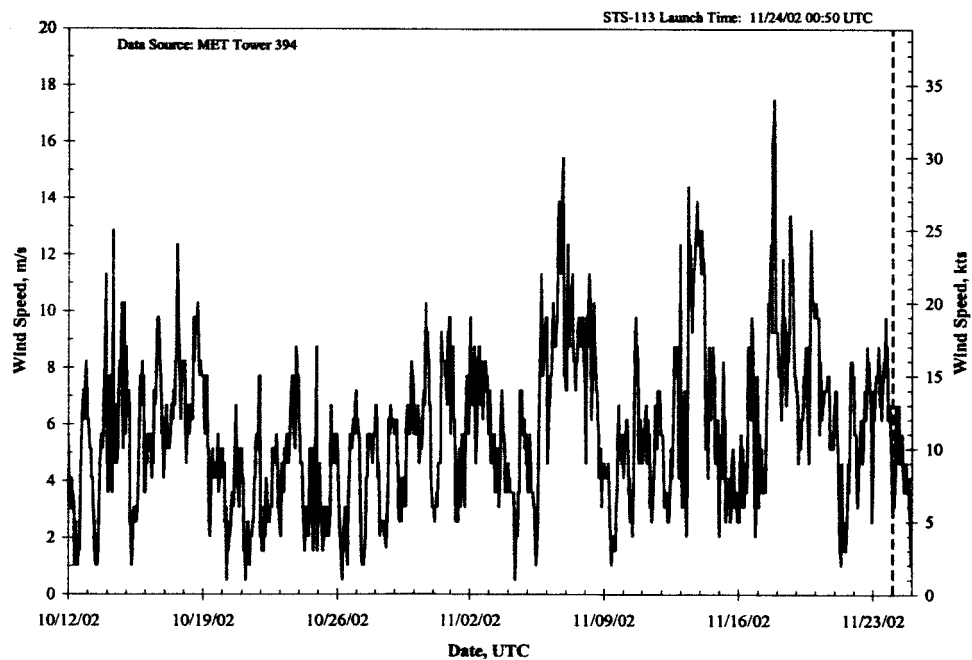


Figure 4. STS-113 Hourly wind speed at 18 m (60 ft.).

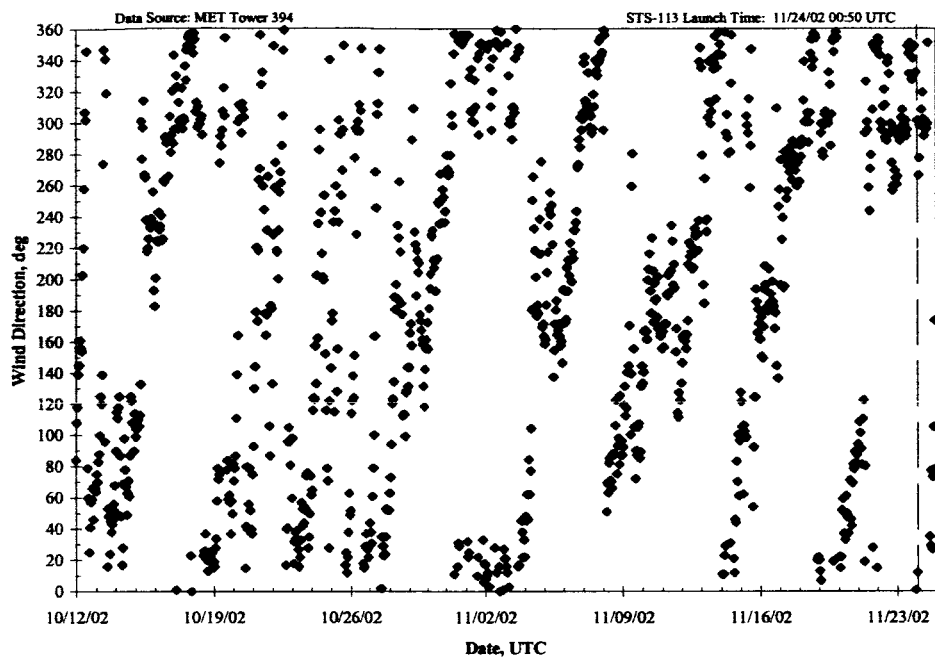


Figure 5. STS-113 Hourly wind direction at 18 m (60 ft.).

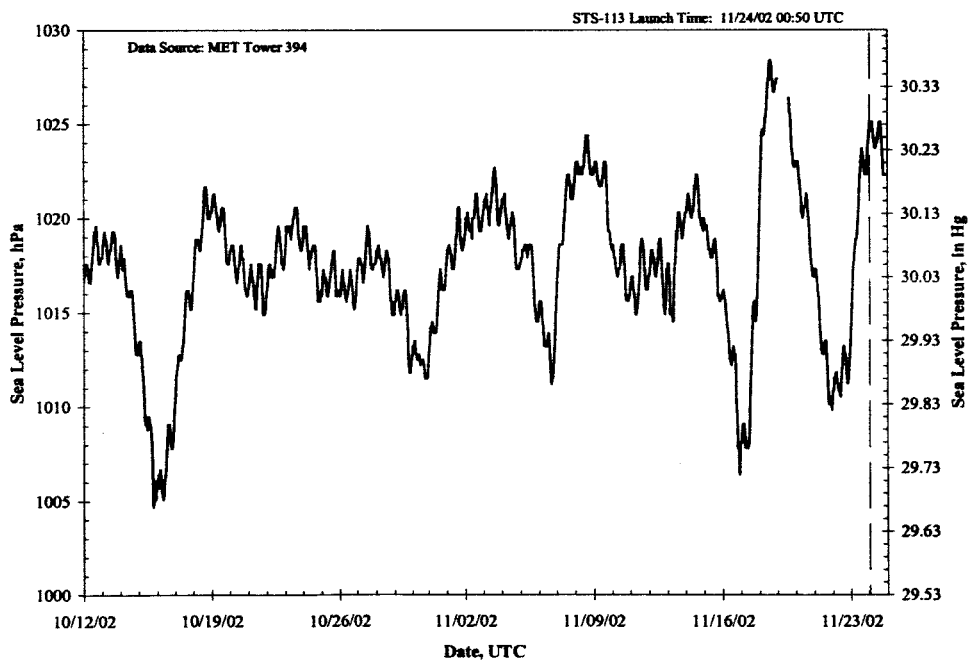


Figure 6. STS-113 Hourly sea level pressure.

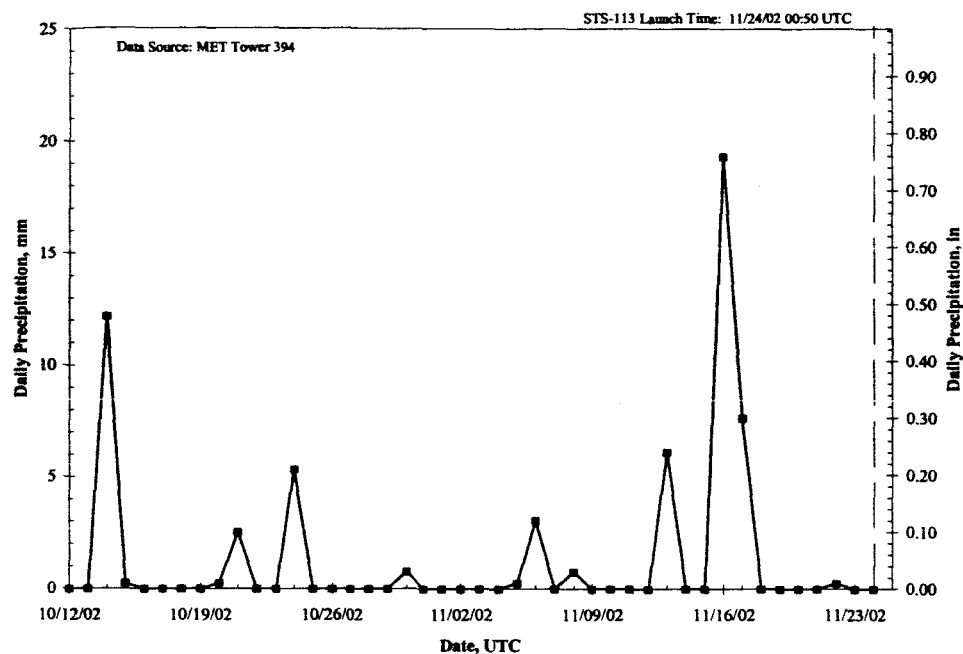


Figure 7. STS-113 Daily precipitation totals.

B. T-0 Meteorological Data Summary

Table 3 presents a summary of the T-0 (liftoff) meteorological conditions for each of the Space Shuttle missions. Data presented includes temperature, relative humidity, wind speed, and wind direction.

Table 3. T-0 (liftoff) meteorological conditions for all Space Shuttle missions.

Mission	Launch Date	Time (UTC)	Temperature (°C)	Relative Humidity (%)	Sea Level Pressure (hPa)	Wind Speed (m/s)	Wind Direction (deg)
STS-1	1981.04.12	12:00	21.1	82	1023.7	3.6	125
STS-2	1981.11.12	15:10	22.8	61	1016.9	8.2	345
STS-3	1982.03.22	16:00	24.4	71	1016.6	2.1	050
STS-4	1982.06.27	15:00	29.1	70	1020.7	1.8	133
STS-5	1982.11.11	12:19	22.0	59	1023.3	6.7	090
STS-6	1983.04.04	18:30	22.8	55	1019.0	3.9	063
STS-7	1983.06.18	11:33	25.1	80	1015.2	1.8	010
STS-8	1983.08.30	06:32	23.9	97	1011.9	2.7	269
STS-9	1983.11.28	16:00	24.4	83	1015.9	5.8	183
41-B	1984.02.03	13:00	16.7	75	1018.0	0.0	000
41-C	1984.04.06	13:58	15.8	56	1015.6	6.5	320
41-D	1984.08.30	12:42	26.2	81	1018.0	0.9	106
41-G	1984.10.05	11:03	23.3	60	1021.7	5.0	073

Table 3. (continued)

Mission	Launch Date	Time (UTC)	Temperature (°C)	Relative Humidity (%)	Sea Level Pressure (hPa)	Wind Speed (m/s)	Wind Direction (deg)
51-A	1984.11.08	12:15	19.9	64	1023.4	7.0	024
51-C	1985.01.24	19:50	17.7	46	1018.0	5.2	228
51-D	1985.04.12	13:59	20.7	55	1026.4	6.1	082
51-B	1985.04.29	16:02	27.4	65	1013.5	3.5	005
51-G	1985.06.17	11:33	22.8	91	1020.7	0.9	201
51-F	1985.07.29	21:00	28.3	72	1018.0	4.5	101
51-I	1985.08.27	10:58	24.3	86	1023.0	4.3	073
51-J	1985.10.03	15:15	28.2	79	1019.3	5.2	213
61-A	1985.10.30	17:00	27.8	72	1006.4	3.9	217
61-B	1985.11.27	00:29	22.7	81	1020.9	3.1	165
61-C	1986.01.12	11:55	12.0	84	1021.3	4.7	323
51-L	1986.01.28	16:38	2.6	27	1026.1	6.1	331
STS-26	1988.09.29	15:37	28.9	56	1019.0	4.2	058
STS-27	1988.12.02	14:31	13.9	50	1027.8	7.8	314
STS-29	1989.03.13	14:57	17.8	78	1019.3	5.2	242
STS-30	1989.05.04	18:47	26.1	57	1020.0	6.6	106
STS-28	1989.08.08	12:37	26.7	80	1011.9	3.8	252
STS-34	1989.10.18	16:54	30.0	52	1015.2	4.1	193
STS-33	1989.11.23	00:23	18.9	80	1013.2	5.2	208
STS-32	1990.01.09	12:35	12.2	100	1020.7	2.1	246
STS-36	1990.02.28	07:50	18.3	71	1026.8	7.2	072
STS-31	1990.04.24	12:34	22.2	63	1020.0	5.7	080
STS-41	1990.10.06	11:47	27.2	73	1018.3	7.2	090
STS-38	1990.11.15	23:48	21.1	63	1025.7	8.8	084
STS-35	1990.12.02	06:49	21.7	61	1024.0	6.6	088
STS-37	1991.04.05	14:23	22.8	84	1025.6	5.7	074
STS-39	1991.04.28	11:33	22.2	95	1014.9	3.9	191
STS-40	1991.06.05	13:25	23.9	83	1020.0	2.1	234
STS-43	1991.08.02	15:02	27.8	73	1018.6	5.2	170
STS-48	1991.09.12	23:11	25.0	71	1014.6	3.8	074
STS-44	1991.11.24	23:44	12.2	48	1019.6	2.6	301
STS-42	1992.01.22	14:53	17.2	86	1022.0	3.1	038
STS-45	1992.03.24	13:13	18.9	72	1018.0	7.2	359
STS-49	1992.05.07	23:40	17.2	70	1013.5	4.1	322
STS-50	1992.06.25	16:12	28.3	72	1013.2	6.9	151
STS-46	1992.07.31	13:57	28.9	76	1020.3	3.2	310
STS-47	1992.09.12	14:23	27.8	70	1020.1	5.0	044
STS-52	1992.10.22	17:10	25.0	49	1027.7	8.4	048
STS-53	1992.12.02	13:24	11.1	87	1020.0	3.1	215
STS-54	1993.01.13	13:59	21.1	94	1022.0	2.9	180
STS-56	1993.04.08	05:29	18.3	74	1017.3	5.1	065
STS-55	1993.04.26	14:50	25.0	70	1019.2	6.2	173

Table 3. (continued)

Mission	Launch Date	Time (UTC)	Temperature (°C)	Relative Humidity (%)	Sea Level Pressure (hPa)	Wind Speed (m/s)	Wind Direction (deg)
STS-57	1993.06.21	13:07	28.3	65	1019.1	3.1	091
STS-51	1993.09.12	11:45	22.8	98	1020.0	2.0	294
STS-58	1993.10.18	14:53	25.6	72	1017.3	3.2	316
STS-61	1993.12.02	09:26	18.9	84	1024.4	1.8	070
STS-60	1994.02.03	12:10	7.2	82	1027.8	4.2	318
STS-62	1994.03.04	13:53	11.7	57	1018.3	5.0	285
STS-59	1994.04.09	11:05	22.0	81	1024.0	9.8	100
STS-65	1994.07.08	16:43	30.1	72	1023.4	4.7	100
STS-64	1994.09.09	22:23	28.9	75	1016.9	3.8	111
STS-68	1994.09.30	11:16	25.8	75	1016.7	5.2	070
STS-66	1994.11.03	17:00	24.4	65	1022.4	5.2	065
STS-63	1995.02.03	05:22	13.2	83	1018.7	5.2	239
STS-67	1995.03.02	06:38	17.6	87	1014.0	4.8	257
STS-71	1995.06.27	19:32	29.6	83	1016.0	4.0	089
STS-70	1995.07.13	13:42	28.4	80	1016.7	2.7	051
STS-69	1995.09.07	15:09	28.9	77	1011.9	3.3	160
STS-73	1995.10.20	13:53	25.1	99	1012.6	2.8	297
STS-74	1995.11.12	12:31	9.8	82	1019.0	5.0	301
STS-72	1996.01.11	09:41	4.9	87	1020.1	4.2	290
STS-75	1996.02.22	20:18	22.7	78	1014.6	2.9	064
STS-76	1996.03.22	08:13	7.3	88	1016.0	3.8	253
STS-77	1996.05.19	10:30	21.3	95	1018.7	0.8	239
STS-78	1996.06.20	14:49	28.4	77	1015.6	0.8	266
STS-79	1996.09.16	08:55	26.0	86	1014.0	4.2	153
STS-80	1996.11.19	19:56	25.1	49	1011.9	3.2	240
STS-81	1997.01.12	09:27	16.2	79	1020.1	4.3	343
STS-82	1997.02.11	08:55	11.1	94	1021.4	3.3	299
STS-83	1997.04.04	19:21	23.7	50	1021.4	4.5	127
STS-84	1997.05.15	08:08	21.2	82	1015.3	2.5	300
STS-94	1997.07.01	18:02	28.7	74	1014.0	4.6	035
STS-85	1997.08.07	14:41	28.3	81	1017.4	2.8	020
STS-86	1997.09.26	02:34	26.2	92	1010.6	3.4	188
STS-87	1997.11.19	19:46	20.2	69	1020.6	6.4	358
STS-89	1998.01.23	02:48	20.0	89	1016.7	7.9	149
STS-90	1998.04.17	18:19	27.0	63	1018.0	6.3	144
STS-91	1998.06.02	22:06	35.4	54	1009.6	5.3	232
STS-95	1998.10.29	19:20	24.9	53	1015.2	2.9	016
STS-88	1998.12.04	08:36	22.2	83	1020.1	3.4	133
STS-96	1999.05.27	10:50	20.9	96	1016.7	2.9	235
STS-93	1999.07.23	04:31	25.6	89	1017.3	1.4	233
STS-103	1999.12.20	00:50	18.9	74	1016.7	2.7	312
STS-99	2000.02.11	17:43	19.3	60	1020.7	5.5	155

Table 3. (continued)

Mission	Launch Date	Time (UTC)	Temperature (°C)	Relative Humidity (%)	Sea Level Pressure (hPa)	Wind Speed (m/s)	Wind Direction (deg)
STS-101	2000.05.19	10:11	22.2	77	1022.4	3.4	128
STS-106	2000.09.08	12:46	27.2	80	1014.6	4.1	008
STS-92	2000.10.11	23:17	22.8	67	1020.6	6.8	050
STS-97	2000.12.01	03:06	17.2	65	1022.4	3.9	007
STS-98	2001.02.07	23:13	18.3	83	1024.7	2.7	059
STS-102	2001.03.08	11:42	5.6	71	1018.6	3.6	289
STS-100	2001.04.19	18:41	20.6	38	1026.1	3.3	076
STS-104	2001.07.12	09:04	24.7	95	1014.6	4.0	218
STS-105	2001.08.10	21:10	29.1	76	1016.6	4.9	103
STS-108	2001.12.05	22:19	23.2	80	1023.4	7.2	052
STS-109	2002.03.01	11:22	15.6	73	1025.7	6.3	066
STS-110	2002.04.08	20:44	24.4	51	1023.4	7.9	131
STS-111	2002.06.05	21:23	28.9	73	1015.2	4.9	105
STS-112	2002.10.07	19:46	28.3	69	1013.5	6.4	020
STS-113	2002.11.24	00:50	13.9	75	1024.0	2.7	004
STS-107	2003.01.16	15:39	18.3	68	1024.0	0.8	173

V. Conclusion

A summary of the types of meteorological data recorded during Space Shuttle pad exposure periods has been presented. A NASA Technical Memorandum with a full set of data for each Space Shuttle mission is being prepared for publication in 2005. All the data referenced in this paper are available from the Natural Environments Branch at Marshall Space Flight Center.

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