1.2 THE JOHNSON SPACE CENTER LIGHTNING WATCH AND WARNING PROGRAM

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1. INTRODUCTION

The National Weather Service (NWS) Spaceflight Meteorology Group (SMG) provides local weather watch and warning support to NASA's Johnson Space Center (JSC) (Brody et al., 1997). This local support includes the issuance of lightning watches and warnings for the Center. A lightning **watch** (officially called a **Lightning Advisory**) is intended to provide select customers with 30 minutes advance notice of cloud-to-ground lightning occurrence within 6 miles of the Center. This allows customers to curtail outdoor activities prior to the development of a hazard. A lightning **warning** (officially called a **Lightning Alert**) provides the entire JSC community notice that lightning is occurring within 6 miles of the Center. These lightning watch and warning products are used for both daily operations and public events such as the JSC Open House.

This paper will describe the development of the JSC lightning protection policy, along with procedures for disseminating the watch and warning information. A discussion of lightning forecasting tools will be included. Some forecaster challenges will be explored. Lightning advisory verification statistics for calendar year 2005 will be presented. This paper will conclude with a brief summary.

2. JSC LIGHTNING PROTECTION POLICY

The development of a JSC lightning protection policy has been ongoing since 2000. In addition to local experience, the recommendations of the American Meteorological Society Lightning Safety Group (Holle et al., 1999) were used as a resource for developing the JSC policy. The process was initially impeded by the lack of a perceived threat of lightning risk and concerns about defining appropriate responses to the threat. While the policy was being developed, weather impacts to two heavily attended public events that were held at the Johnson Space Center helped to eliminate the barriers to implementing the policy.

In June 2005, Chapter 5.9 "Weather Safety" was added to the JSC Safety and Health Handbook (JSC document number JPR 1700.1). For reference, Chapter 5.9 in its entirety, which includes all weather hazards, not just lightning, can be found at the following URL: http://jschandbook.jsc.nasa.gov/. The "Weather Safety" Chapter states that: "You must follow this Chapter if:

- You work at JSC or a JSC field site as a civil servant or contractor employee.
- You are a line manager, facility manager, or contractor safety representative."

Within the "Weather Safety" Chapter, there is a section dedicated to lightning. The lightning policy provides the following guidance: "If lightning is occurring in the JSC area, take the following steps immediately:

- Suspend all outdoor activities, including construction and landscaping work and move indoors if possible.
- Move to a protected location. JSC buildings occupied as daily work areas (office buildings and laboratories) can be considered to be protected safe locations during a lightning event. If you cannot safely reach an office or laboratory building, a metal enclosed vehicle with the windows rolled up will provide better protection than being outdoors.
- Stay out of direct contact with plumbing, piping, window frames, or other metallic objects. You may continue to use phones and computers because they are isolated. If in an automobile, stay away from any metal in the vehicle.
- Monitor weather conditions."

As a component of the lightning protection policy described in Chapter 5.9 "Weather Safety", SMG provides JSC organizations and individuals two lightning products: (1) Lightning Advisory (Watch), and (2) Lightning Alert (Warning). It should be noted that the Lightning Watch ("Advisory") product is not described in Chapter 5.9 "Weather Safety". A graphical depiction of the Advisory and Alert definitions, as well as terms used in the

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verification program, is shown in Figure 1. These products will be described in detail in the sub-sections below. The lightning products receive a wide distribution via phone notifications, e-mail, the JSC intranet, and the JSC closed-circuit TV system during routine operations. In addition, event organizers are required to develop a weather plan for all on-site special events (Examples: JSC Open House, Ballunar Liftoff Festival).

Although policy is important, the authors feel the most important component of the JSC program is the lightning safety education program. An effective education program involves initial training and periodic review and re-education. In order to educate our customers following implementation of the new policy, the lightning policy and products were advertised to the JSC community through the Center newsletter and management briefings. Also, all civil servant and contractor employees are required to complete an annual Hazard Communication course that has been updated to include a section on lightning safety and the JSC lightning policy. Lastly, JSC placed special emphasis on lightning safety as a mandatory topic at the 2005 JSC Safety and Total Health Day. The presentation can be found at: http://www.srh.noaa.gov/smg/JSCLtgSafety.ppt

2.1 Lightning Advisory ("Watch")

The Lightning Advisory product provides customers with a *forecast* for lightning to occur within 6 miles of JSC. The Lightning Advisory product is not issued to the entire JSC community. Only select customers receive notification based on their need to prepare for the lightning conditions (See Table 1). SMG's goal is to issue the Lightning Advisory product with a 30-minute lead time before the onset of lightning observed within 6 miles of JSC. The 30-minute lead time is based on the time to transfer from commercial power to backup (generator driven) power in the Mission Control Center at JSC. When a Lightning Advisory is issued, the SMG forecaster contacts specific customers individually via phone or NASA's Digital Voice Intercommunication System (DVIS). These customers are also contacted individually when the Advisory is canceled to allow them to return to normal operations.

2.2 Lightning Alert ("Warning")

The Lightning Alert product provides a general notice to the entire JSC community that lightning is *observed* within 6 miles of JSC. While the Lightning Advisory product is only distributed via voice to a select group of customers, SMG uses three methods (listed in order of priority) to issue the Lightning Alert product Center wide: (1) Phone/DVIS, (2) Electronic-JSC Emergency Notification System(JENS), and (3) NASA TV Banner. Notification by phone/DVIS is similar to that of the Lightning Advisory One of the customers contacted via phone provides the Lightning Alert NASA TV banner; a "crawler" that scrolls along the bottom of a NASA JSC TV Channel. The JENS is used to provide an electronic means of notification. When a Lightning Alert is issued via JENS, an email is sent to a "JENS weather distribution list". Also, for the general JSC community, a web link is provided on the JSC Internal home page. Figure 2 shows an example Lightning Alert web link on the JSC home page. Figure 3 shows the window that appears when a person clicks on the Lightning Alert web link from the JSC home page. Following the guidelines of the "30/30 rule", the Lightning Alert is canceled 30 minutes after the last observed lightning flash within 6 miles of JSC.

3. FORECAST TOOLS AND CHALLENGES

SMG has access to real-time cloud-to-ground (CG) lightning data from the National Lightning Detection Network (NLDN) via 3 different software display systems: (1) Man computer Interactive Data Access System (McIDAS), (2) Advanced Weather Interactive Display System (AWIPS), and (3) Meteorlogix StormSentry ®. While having access to numerous systems can be beneficial, it can also present challenges to the forecaster due to data latency issues and data inconsistencies. The sub-sections below will discuss these issues and present other lightning forecast tools and challenges.

3.1 Lightning Forecast Tools

SMG primarily uses CG lightning and radar to forecast lightning. This section will describe the various ways in which these data can be used to assist in making lightning forecasts. Other potential lightning forecast tools that SMG is not currently using operationally, but is currently evaluating or may be evaluating in the future, will also be discussed.

SMG forecasters use the NLDN CG lightning data and NEXRAD WSR-88D data in some combination to provide them with the best look at

current and potential future (forecast) lightning. SMG uses the WSR-88D radar-based rules to make short term predictions of lightning (Garner et al, 2002). These rules are derived from studies by Gremillion and Orville (1998), Dye et al (1989), and others.

While CG lightning and radar have proven to be helpful in some ways, SMG feels there are other potential lightning forecast tools. Of particular interest is total lightning data. As discussed in Oram et. al (2005), "it has been SMG's experience that approximately five minutes lead time is lost when applying guidelines developed by Gremillion and Orville when the forecasts are verified with LDAR and NLDN data rather than only NLDN, as was done in the original study." As part of the Space Shuttle forecast responsibilities, SMG has access to total lightning data over the Kennedy Space Center (KSC) area via the KSC LDAR (Lightning Detection and Ranging) system (Lennon and Maier, 1999). Unfortunately, SMG does not currently have access to total lightning data over the JSC area. However, SMG hopes to have access to the Southeast Texas LDAR II data in the future. In addition to total lightning data, SMG is currently evaluating ThorGuard®, a system that claims to predict lightning occurrence.

3.2 Lightning Advisory Challenges

Lightning Advisory challenges for the forecaster include determining when to issue the advisory and when to cancel the advisory. Both decisions are often based on the application of conceptual models and rules of thumb for lightning occurrence. These models and rules of thumb are typically related to radar and satellite signatures.

As noted previously, Gremillion and Orville (1999) provide forecasters a set of possible empirical rules of thumb for predicting the onset of lightning in a particular cell. These rules of thumb are based on radar reflectivity signatures. Although the original study was based on observations of thunderstorms in the vicinity of Kennedy Space Center in Florida, SMG forecasters have found the rules to be generally valid for convection in other parts of the United States. However, SMG has also anecdotally found the Gremillion and Orville rules of thumb over forecast cloud-to-ground lightning occurrence for convection in the Houston area during the winter months.

Another forecaster challenge is predicting lightning associated with thunderstorm anvils which advect downwind from the parent cumulonimbus cloud. Observations of cloud-to-ground lightning occurring in association with the anvils have been reported in the literature; Engholm et al (1990) and Stolzenburg (1990), for example. However, the rules of thumb for predicting the threat of cloud-to-ground lightning from anvils appear to be limited.

Predicting the cessation of lightning may be a more significant challenge than predicting lightning onset. Thunderstorm anvils present a challenge in this area as well; one example being when an advisory has been issued and anvils persist within the warning area. Another situation presenting a cessation challenge is the presence of a stratiform precipitation area behind a convective system (a winter challenge for SMG). Again, lightning can occur within the trailing stratiform region although its occurrence is infrequent and difficult to predict. Better conceptual models and rules of thumb are needed for ending advisories in these circumstances.

A case showing the difficulty in predicting the onset and cessation of organized convective lines is shown in Figure 4. The figure shows hourly snapshots of a convective line moving through JSC between 23:00 UTC on 31 Oct and 02:00 UTC on 1 Nov 2005. At 22:59 UTC, the line is well northwest of JSC with cirrus anvil advecting toward the warning area (Figure 4a). Although a majority of the lightning is associated with the convection in the line, a single positive cloud to ground flash was observed approximately 6 miles from JSC under the anvil but well ahead of the line. The line moves through JSC by 01:00 UTC on 1 Nov bringing several lightning flashes to the area. However, a lightning threat persists in the trailing stratiform region behind the line where a single cloud-to-ground flash occurs between 01:00 and 02:00 UTC (Figure 4d). Although the forecaster has high confidence that lightning is likely to occur, the challenge is determining the time to issue and cancel the advisory to account for the lightning associated with the anvil and trailing stratiform rain without causing excessive impacts to SMG's customers.

3.3 Lightning Alert Challenges

The primary challenge associated with lightning alerts at SMG is assessing the quality of the cloud-to-ground flash data from NLDN. In many instances, forecasters have complementary sources of information to assess the quality of meteorological data. For example, WSR-88D

Doppler radar wind measurements, wind profilers, and surface-based anemometers provide complementary information that allows the forecaster to assess the quality of any single observation of the wind. However, the NLDN CG lightning is the only data source available to SMG forecasters that provides CG flash locations as a direct measurement. The quality assessment of the lightning data, therefore, is often based on the same conceptual models and rules of thumb that are used to issue the advisory -- not an ideal situation for identifying problems with the conceptual models.

Two specific issues that forecasters must resolve in regards to the quality of the data are: 1) the type of flash (CG or intracloud/cloud-to-air), and 2) the location accuracy. Although the NLDN flashes are identified as CG flashes, Vaisala believes that some of the weak, positive (normalized strength between 0 and about 15 kA) CG flashes may in fact be intracloud flashes that are misreported as CG (Ron Holle, personal communication). Therefore, the determination of the type of flash can be important for assessing the location accuracy. An intracloud flash that is accurately located should not be discounted by the forecaster when considering the need for a lightning advisory or alert. However, the authors are not aware of any documented study that has estimated the location accuracy of these weak, positive CG flashes. In addition, although negative CG flashes are deemed accurate, there is some error associated with the flash location. Information about the location accuracy of NLDN flashes available to Vaisala is not available to the forecasters in real-time.

The example shown in Figure 4 also depicts the difficulty in assessing the quality of the NLDN data. Although the AWIPS display in Figure 4 shows the polarity of the flash, the normalized strength is not readily available. In addition, the flash location is displayed with no estimate of the location uncertainty. Note that both the isolated, single flashes that occurred within the JSC warning area were positive flashes. Examination of additional information in the McIDAS based system shows that both of these positive flashes had a normalized strength less than 10 kA. The isolated negative CG flashes that were also occurring under the anvil (Figure 4a) and within the stratiform region (Figure 4d) complicate the interpretation of the data and the assessment of the likelihood of lightning occurring in the areas.

It is hoped that SMG will gain access to the Houston LDAR II data being installed by Texas A&M University. Our experience with the KSC LDAR system has pointed out the value of having this complementary data.

4. Forecast Skill and Lightning Events During 2005

Although SMG has been issuing a Lightning Advisory product for several years, calendar year 2005 was the first year for which these products were systematically verified. NLDN data stored in the SMG McIDAS-based system were used as the primary verification data. These NLDN data are broadcast by Meteorlogix and decoded into McIDAS compatible format using locally developed software. The NLDN dataset in AWIPS was used as a secondary source of information for the verification.

As discussed in section 2, Figure 1 contains a graphical depiction of the terms used in the SMG lightning verification program. Although many of these definitions are standard terms used in verification programs, the following definitions are provided to help explain Figure 1 and the following verifcation statistics.

Lightning Event: One or more flashes occurring within 6 miles of JSC separated in time by no more than 30 minutes.

Lightning Alert: A product issued when a Lightning Event occurs during duty hours, cancelled 30 minutes after the last flash in the event occurs.

Lightning Advisory: A product issued when a lightning event is forecast to occur, canceled when the forecaster determines that the threat has ended.

Lead Time: The time that elapses from when a Lightning Advisory is issued until the Lightning Event begins.

Desired Lead Time: The desired amount of time between the issuance of the Lightning Advisory and the onset of a Lightning Event.

Lost Time: The amount of time for which an Lightning Advisory is in effect minus the time for which a Lightning Event (events) is (are) occurring minus the

minimum of either the desired lead time or the actual lead time.

A Lightning Event is determined using only the NLDN data. No attempt is made to determine if the CG flash reported by the NLDN is accurately located. No validity tests have been applied to the NLDN flashes to screen out data (i.e. no screening for weak positive flashes, for example). It is hoped that any errors that remain in the NLDN data after processing by Vaisala are random.

Figure 5 contains a summary of all Lightning Events that occurred in the JSC lightning dataset. Note that some Lightning Events occurred during non-duty hours when comparing the number of events to the number of advisories in the forecast statistics. The majority of Lightning Events were less than one hour in duration. The authors were somewhat surprised by the number of single flash events.

SMG issued sixty-five Advisories during calendar year 2005 through Sept 30th. Thirty-three of the advisories had a positive lead time. Nineteen of the advisories were false alarms. Thirteen of the advisories were issued when the first cloud-to-ground strike occurred (a missed event). Half of the missed events consisted of less than five cloud-to-ground strikes.

Figure 6 summarizes the distribution of lead times for the advisories. The average lead time of the advisories excluding the missed events and false alarms was thirty-five (35) minutes. The majority of lead times were greater than 0 minutes and less than 45 minutes. Figure 7 summarizes the distribution of lost time for the advisories. Although there appears to be no trend in the data, the majority of lost time per advisory was less than 60 minutes with about 12% of the advisories with no lost time.

5. Summary

JSC has recently implemented a Lightning Safety program. SMG issues Lightning Alerts and Lightning Advisories to support the Lightning Safety program. A key component of the program is a strong education program. On average, the Lightning Advisories provide the desired lead time for customers to prepare for lightnging onset. However, there is a need for complementary lightning data such as LDAR and LMA total lightning data to improve accuracy of Advisories and the precision of Alerts. Further lightning research will hopefully improve the conceptual models and rules of thumb for lightning forecasting.

References

Brody, F.C., R.A. Lafosse, D.G. Bellue, and T.D. Oram. 1997: Operations of the National Weather Service Spaceflight Meteorology Group. *Wea. Forecasting,* **12**, 526–544.

Dye, J. E., W. P. Winn, J. J. Jones, and D. W. Breed, 1989: The electrification of New Mexico Thunderstorms. 1. Relationship between precipitation development and the onset of electrification. *J. Geophys. Res.*, **94**, 8643-8656.

Engholm, C.D., E. R. Williams,, and R.M. Dole, 1990: Meteorological and Electrical Conditions Associated with Positive Cloud-to-Ground Lightning. *Mon. Wea. Rev.,* **118**, 470-487

Gremillion, M.S., and R.E. Orville. 1999: Thunderstorm Characteristics of Cloud-to-Ground Lightning at the Kennedy Space Center, Florida: A Study of Lightning Initiation Signatures as Indicated by the WSR-88D. *Wea. and Fcst.* **14**, 640–649.

Holle, R.L., R.E. Lopez and C. Zimmermann, 1999: Updated recommendations for lightning safety – 1998. *Bull. Amer.Meteor. Soc.,* **80**, 2035 – 2041.

Lennon, C, and L. Maier, 1991: Lightning mapping system. *Proceedings of the International Aerospace and Ground Conference on Lightning and Static Electricity*, Cocoa Beach, FL, NASA Conference Publication 3106, Vol. II, 89.1-89.10.

Oram, T.D., T. Garner, and B. Hoeth, 2005: Use of lightning data for Space Shuttle and Soyuz re-entry and landing forecasts at Johnson Space Center. *Conf. on Meteorological Applications of Lightning Data*, Seattle, WA, Amer. Meteor. Soc., CD-ROM, P1.4.

Stolzenburg, Maribeth, 1990: Characteristics of the Bipolar Pattern of Lightning Locations Observed in 1988 Thunderstorms. *Bull. Amer.Meteor. Soc.,* **71**, 1331-1338

Notice

constitute endorsement thereof by the authors, the National Weather Service, the National Aeronautics and Space Administration, or the United States Government. Any such mention is solely for the purpose of fully informing the reader of the resources used to conduct the work reported herein.

The views expressed are those of the author(s) and do not necessarily represent those of the National Weather Service.

TABLE 1. Lightning Advisory Customers and Impact to Operations

Customer	Impact to Operations
Flight Control Team Facilities Coordinators	Transfer power from commercial source to local diesel generators
Energy Systems Test Area	Prohibits use of pyrotechnics
Electronic Systems Test Laboratory	Ceases work on outdoor space antennae systems
Space Center Houston	Ceases public tours of JSC facilities
Special Events (usually involving public on JSC property)	Recommend moving to a lightning safe location for personal safety

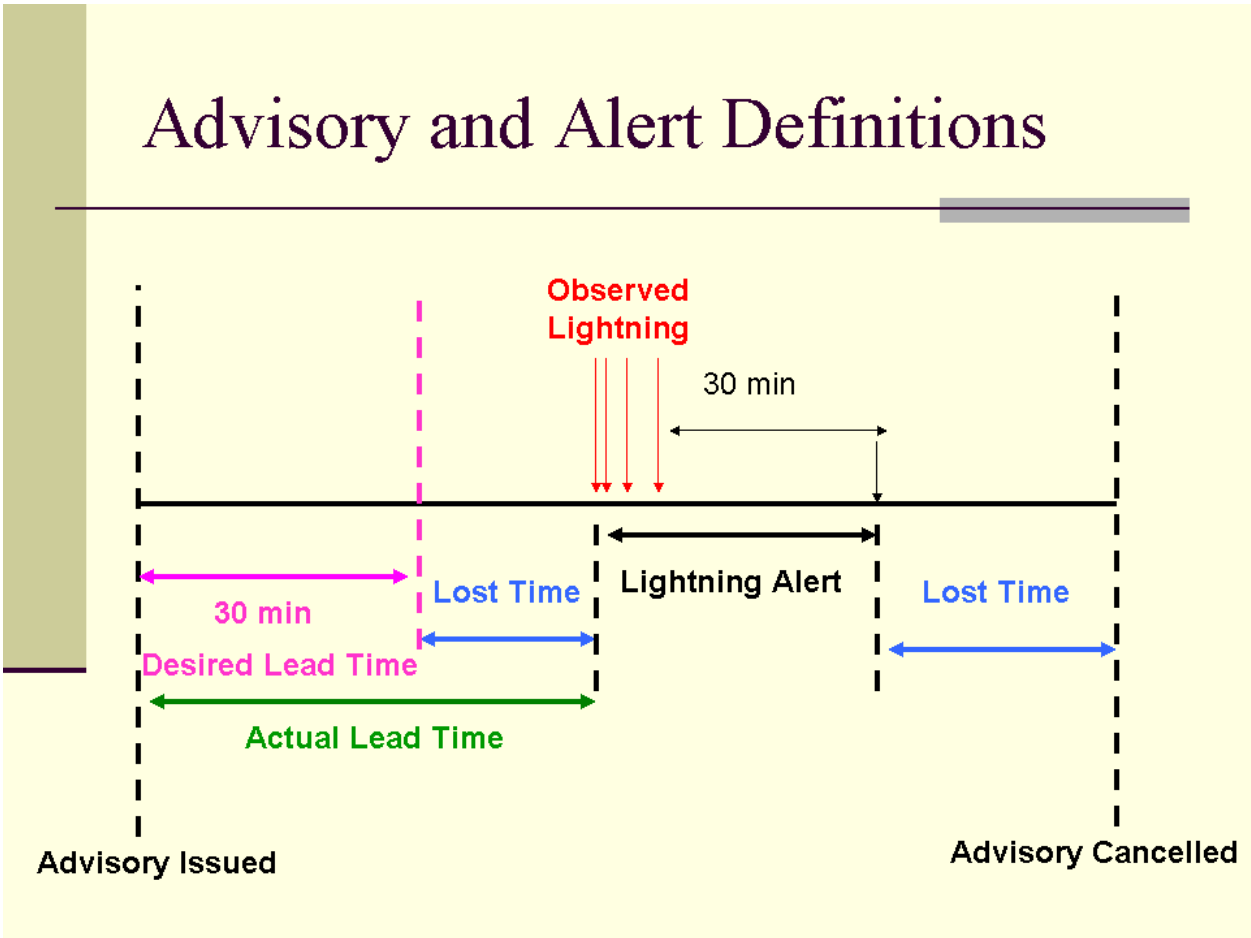

Figure 1. Lightning Advisory and Alert Definitions

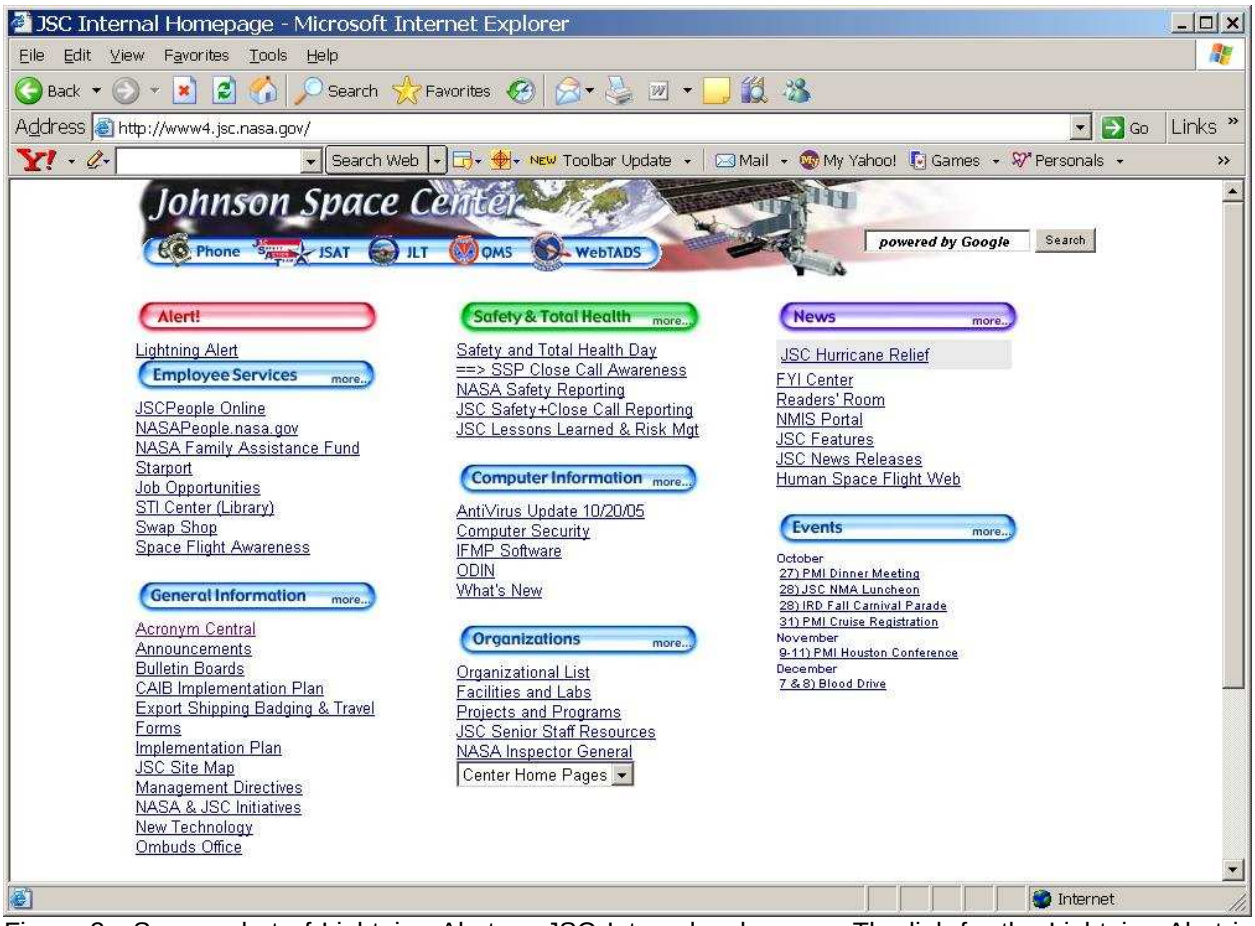

Figure 2. Screen shot of Lightning Alert on JSC Internal web page. The link for the Lightning Alert is found under the "Alert" section in the upper left hand corner of the page.

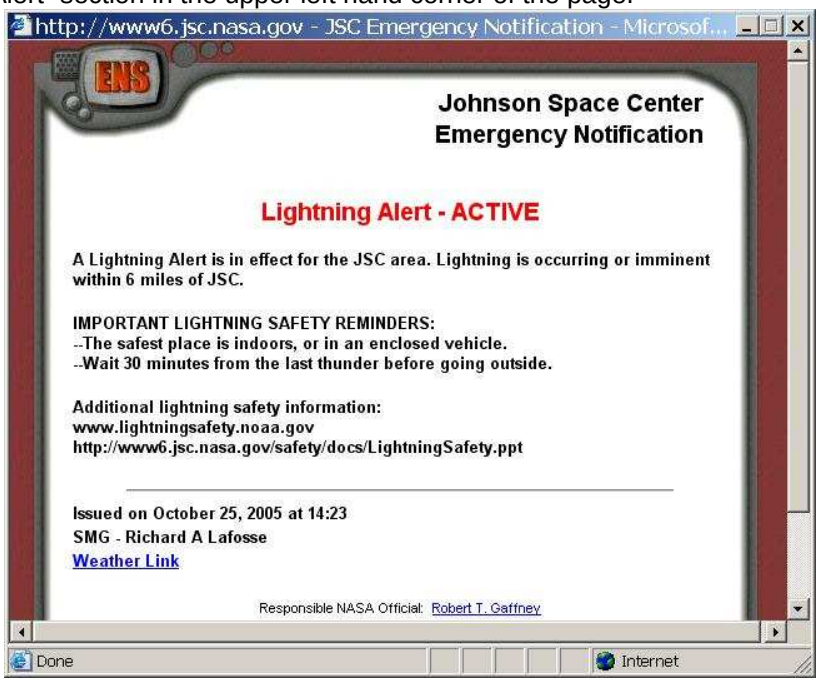

Figure 3. Example Lightning Alert product. This is the popup window that resulted from clicking on the "Lightning Alert" link in Figure 2.

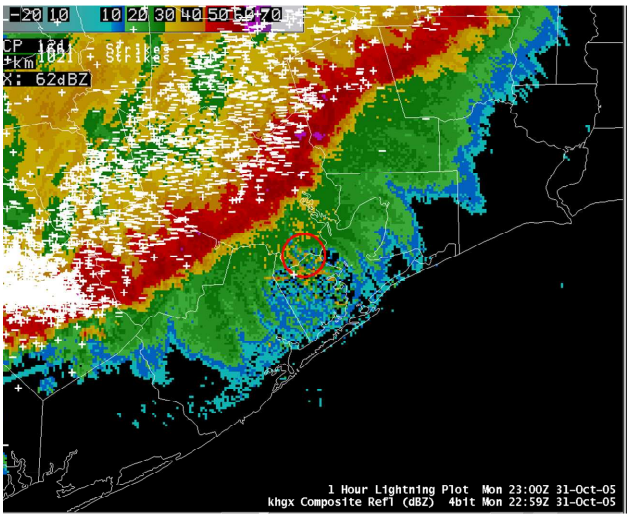

Figure 4 a. Houston Composite Reflectivity Product for 22:59 UTC on 31 Oct 2005. NLDN lightning flashes from 22:00 to 23:00 UTC on 31 Oct are overlaid on the image with positive CG flashes as "+" and negative CG as "-". The 6 statute mile circle around Johnson Space Center appears near the center of the image.

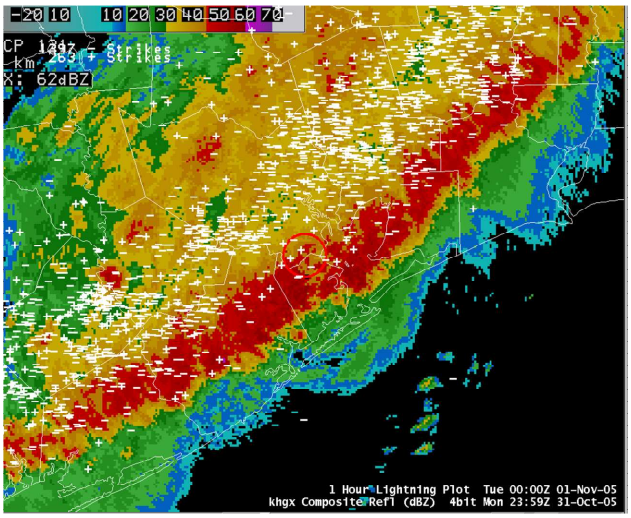

Figure 4 b. Houston Composite Reflectivity Product for 23:59 UTC on 31 Oct 2005. NLDN lightning flashes from 23:00 UTC 31 Oct to 00:00 UTC on 1 Nov are overlaid.

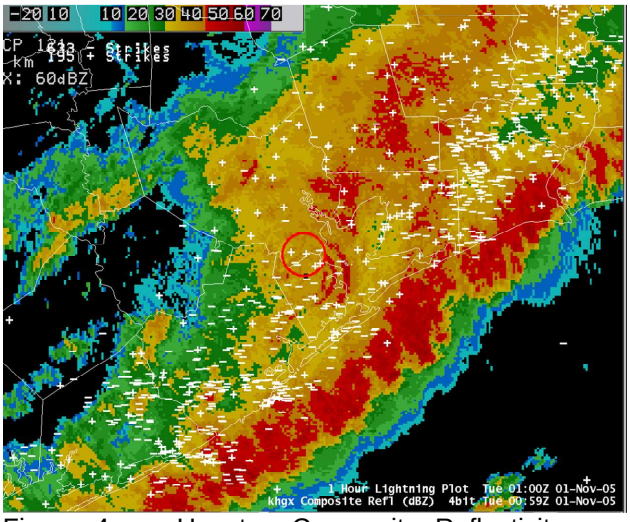

Figure 4 c. Houston Composite Reflectivity Product for 00:59 UTC on 1 Nov 2005. NLDN lightning flashes from 00:00 to 01:00 UTC on 1 Nov are overlaid.

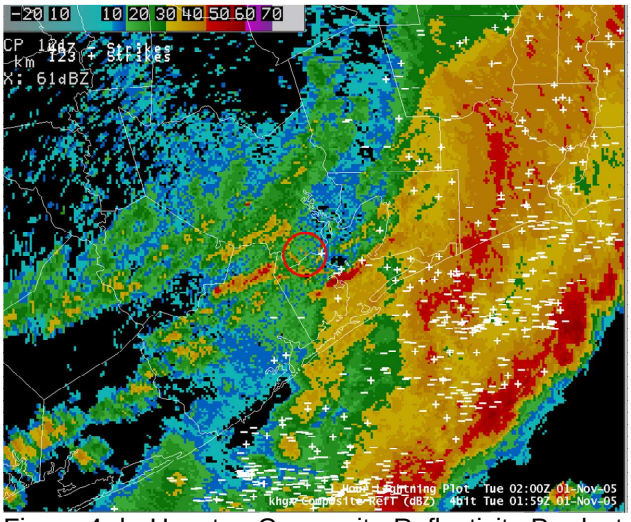

Figure 4 d. Houston Composite Reflectivity Product for 01:59 UTC on 1 Nov 2005. NLDN lightning flashes from 01:00 to 02:00 UTC on 1 Nov are overlaid.

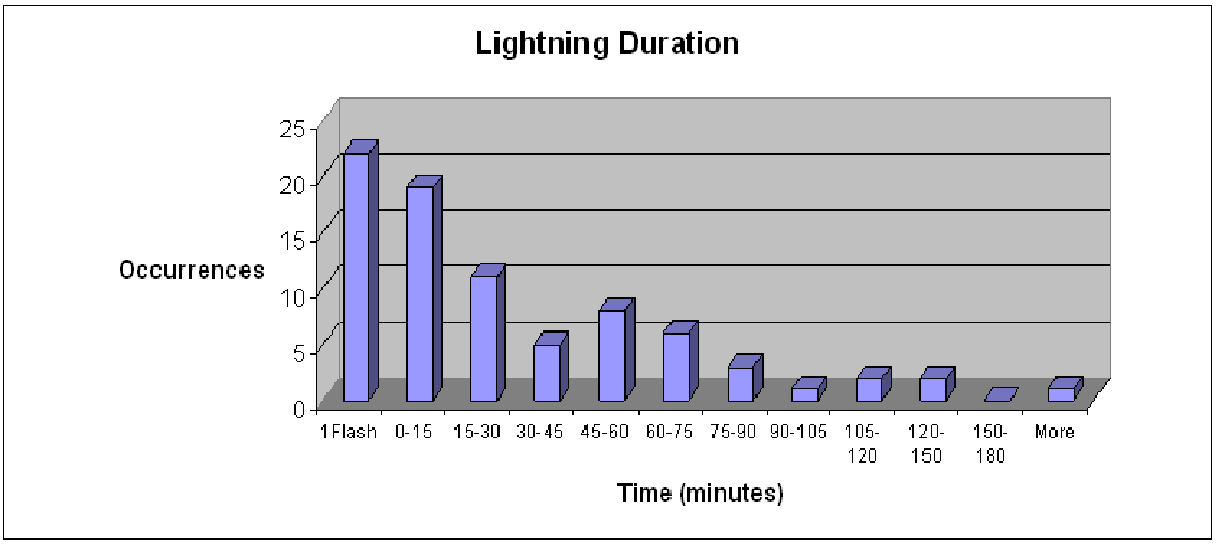

Figure 5. Duration of JSC Lightning Events for January through September 2005.

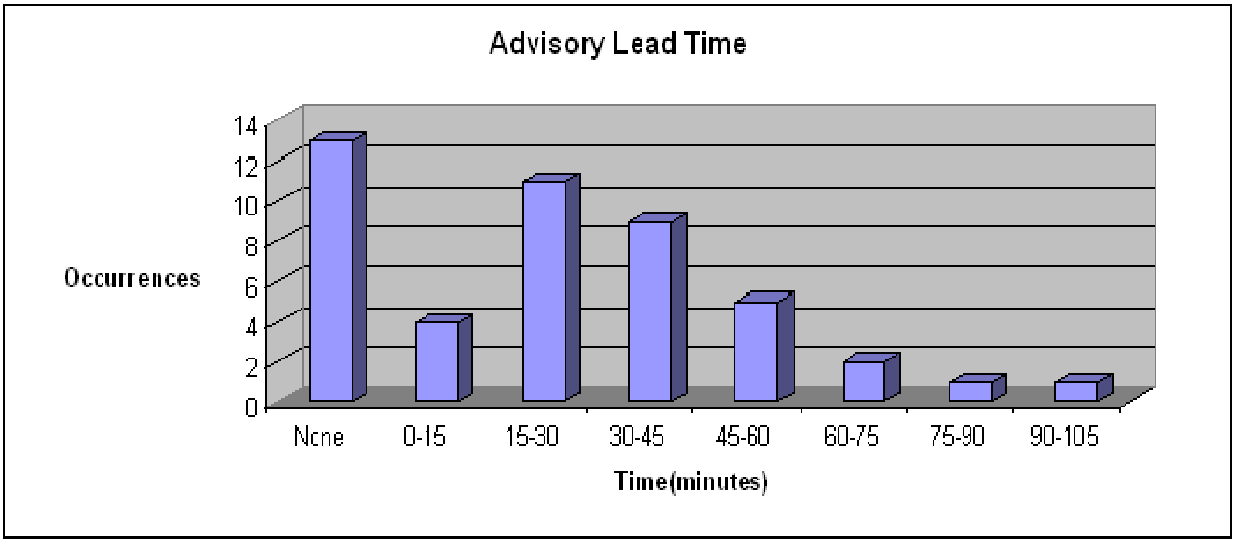

Figure 6. Lightning Advisory Lead Times for January through September 2005.

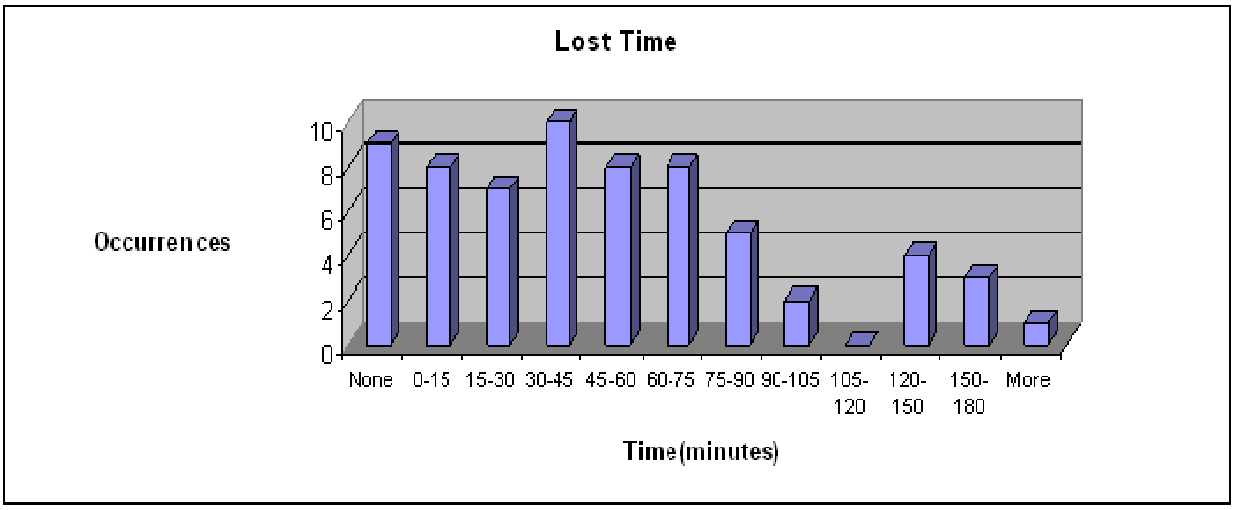

Figure 7. Lightning Advisory Lost Time for January through September 2005.