4.5 FACILITATING THE USE OF ENVIRONMENTAL INFORMATION FOR SPACE LAUNCH DECISIONS

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1. INTRODUCTION

The Air Force's 45th Weather Squadron (45 WS) provides comprehensive operational meteorological services to the Eastern Range (ER) and the Kennedy Space Center (KSC). These services include weather support for resource protection, pre-launch ground processing, and day-of-launch operations for up to 40 launches per year by the Department of Defense, National Aeronautics and Space Administration (NASA), and commercial launch customers.

Launch vehicles present a unique challenge to weather forecasters to ensure both mission success and safety of personnel. This paper addresses the weather launch requirements, instrumentation used to collect the required data and method of dissemination of that information to the launch directors.

2. WEATHER LAUNCH REQUIREMENTS

Two significant items contribute to the difficulty of weather support: (1) location of the ER/KSC complex and (2) the mission. The area of maximum lightning occurrence in the United States is in Central Florida, near the Cape Canaveral Air Force Station (CCAFS)/KSC complex. Consequently, thunderstorms represent the single greatest threat to operations on CCAFS/KSC, bringing deadly lightning and damaging winds. Table 1 shows monthly frequency of thunderstorms for the Shuttle Landing Facility (SLF) in 3-hourly increments, rounded to the nearest whole percent ("#" indicates less than 0.5 percent) based on 25 years (1973-1997) of hourly observations at the SLF (AFCCC, 1998). These climatological data clearly show a thunderstorm maximum in the summer afternoons, reaching 25 percent of hourly observations for 1500 to 1700 Local Standard Time (LST) in July. Days with thunderstorms (as opposed to hourly data) exceed 50 percent in both July and August. The number of cloud-to-ground strikes per year is widely variable within the CCAFS/KSC complex. The annual average ranges from 5 to 13 flashes per km^2 as recorded by the ER Cloud-to-Ground Lightning Surveillance System (CGLSS) (Boyd, et al., 1995).

Launch operations require uniquely specialized support. Weather presents a significant hazard to all phases of spacelift operations (Boyd et al., 1995). During the processing phase, launch vehicles and their payloads are prepared for flight. These activities, which often occur outdoors, can involve propellants, ordnance, and sensitive electronic systems, all at risk from lightning strikes, winds, and precipitation.

During the launch phase, the booster and its payload are at added risk due to the possibility of the vehicle triggering a lightning strike, or wind shear exceeding the booster's structural capability. To assess the triggered lightning threat, the USAF and NASA jointly developed a complex set of lightning launch commit criteria (LCC) (Roeder, et al., 1999). Impact of weather on launches is shown in Table 2. Note that approximately one third of the delays and half the scrubs are weather related.

Table 1
Percent of Hourly Observations with Thunderstorms at the KSC Shuttle Landing Facility (POR: 1973-1997)

LST	APR	MAY	JUN	JUL	AUG	SEP
00-02	#	1	1	2	2	2
03-05	#	1	1	1	1	1
06-08	#	#	2	#	1	1
09-11	2	1	4	2	4	4
12-14	2	3	17	13	15	10
15-17	3	8	23	25	20	15
18-20	4	6	12	13	10	9
21-23	1	3	8	7	7	6

Table 2
Eastern Range Launch Countdowns
(POR: 1 Oct 88-25 Aug 00)

Countdown	**Launch** (on time)	**Launch With *Delay***	***Scrubbed* Launch**
494 (100%)	173 (35%)	146 (30%)	175 (35%)
		Cause of Delay/Scrub	
		User 60 (12%)	User 74 (15%)
		Range 36 (8%)	Range 12 (2%)
		Weather 50 (10%)	Weather 89 (18%)

2.1 LCC Evaluation

Most of the LCC are for triggered lightning. Triggered lightning is an electrical discharge caused by the rocket and electrically conductive exhaust plume passing through a sufficiently strong pre-existing electric field (Figure 1). The triggered lightning process can be viewed as a compression of the ambient electric field until the breakdown potential voltage of air is reached or exceeded, resulting in a triggered lightning strike. While the exhaust plume is conductive primarily due to its high temperature, composition also plays a role (Krider, et al., 1974). Due to this compression, the

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electric fields required for triggered lightning are two orders of magnitude less than those required for natural lightning. Higher magnitude electric fields can be generated by several sources, as covered by the LCC. Some phenomena can generate higher electric fields that occur over a shallow depth and are not a triggered lightning threat, examples include: fog, surf, raindrop fracturing, 'Sunrise Effect' (Marshall, et al. 1999), and powerlines.

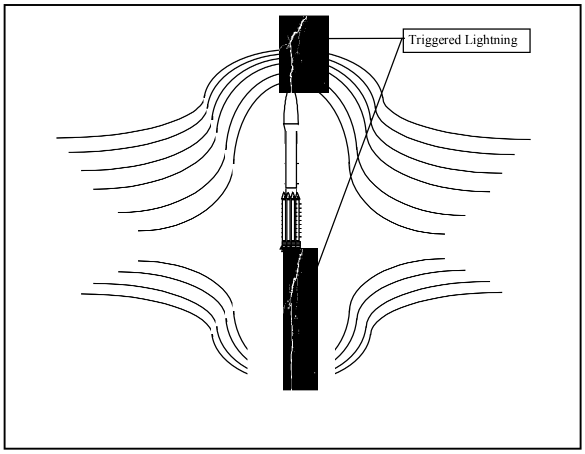

Figure 1. Triggered Lightning

The LCC protect primarily against electric charge generated in the mixed solid-liquid phase of water, either directly at the charge generation site or advected elsewhere after charge generation, e.g. via anvil or debris clouds. However, two LCC are for charge generation from sources other than the mixed phase of water: smoke plume and triboelectrification LCC.

The distinction between triggered and natural lightning is important. Ten of the eleven LCC are for triggered lightning. Even the one natural lightning rule is mostly for triggered lightning, due to charge deposition from the natural lightning, rather than the natural lightning bolt intercepting the rocket.

The current LCC (Table 3) are a set of 11 rules used to avoid the threat of natural and triggered lightning to launches from ER/KSC. These LCC are complex and atypical within operational meteorology. If any LCC is violated during the launch window, then the launch is scrubbed or delayed, depending on available time remaining in the launch window. The same LCC are used for all launch vehicles from ER/KSC and Western Range (WR), except for Trident ballistic missiles at the ER, which have different operational requirements (Roeder, et al. 1999).

2.2 Upper-Air Evaluation

The Range Technical Services contractor, currently Computer Sciences Raytheon, provides a wide range of meteorological observations, including quality control (QC) of upper air winds, and systems maintenance during the countdown. The upper-air QC is time critical to ensure safety of the launch vehicles.

Upper-air data are provided to each customer, who assesses the impact to their launch vehicle. Smith and Adelfang (1992), and Tiwari and Schultz (1996) detailed how this is accomplished for the Shuttle and Titan IV, respectively.

Table 3
Lightning Launch Commit Criteria

LCC
1. Lightning
2. Cumulus Clouds
3. Anvil Clouds a) Attached Anvil b) Detached Anvil
4. Debris Clouds
5. Disturbed Weather (moderate precipitation, bright band)
6. Thick Cloud Layers
7. Smoke Plumes
8. Surface Electric Fields
9. Electric Fields Aloft (not in use, due to lack of electric field profiles)
10. Triboelectrification
11. "Good Sense" Rule (suspected triggered lightning threat, not explicitly listed in other LCC)

2.3 Safety Support

The ER Safety Office has multiple weather support requirements, including observation of the vehicle during ascent, toxic hazard forecasts, potential blast effects of an explosion at the launch pad, and debris fallout in case of an accident. All are very weather sensitive.

Range Safety must assess the safety risk of each operation at the Eastern Range. A key element for the Range Safety Office to correctly ensure safety of government personnel and the civilian population is weather data ingested into the safety models for risk assessments. A summary of current weather systems and data provided to Range Safety, and the models/techniques used by Range Safety to make those assessments is documented by Boyd, et al., 1999.

3. ER WEATHER SYSTEMS

For the 45 WS to fully support AF and NASA, an extensive suite of instrumentation is currently deployed throughout the CCAFS and KSC area as described by Harms et al. (1997). The ER meteorological instrumentation includes: four independent lightning detection systems, an extensive upper-air system (consisting of radars, balloons, Jimspheres, and rocketsondes), hundreds of boundary layer sensors, two weather radars, and direct GOES weather satellite read-out. A major effort is under way to replace the current upper-air system with a GPS based system. All data are displayed in Range Weather Operations (RWO), mainly on a Meteorological Interactive Data Display System (MIDDS), also in the process by being replaced.

3.1 Lightning Systems

The current Launch Pad Lightning Warning System (LPLWS), a network of 31 field mills distributed in and around the launch and operations areas of CCAFS and KSC, was upgraded as part of a detailed look at weather support from 1985-1989. NASA and the Air Force agreed on a joint project to upgrade the LPLWS. The NASA Marshall Space Flight Center developed the LPLWS field mill instruments and base station computer. The USAF 45th Space Wing (45 SW) developed the LPLWS host computer and real-time display and also integrated and tested the overall system. Location of the current field mills is shown in Figure 2.

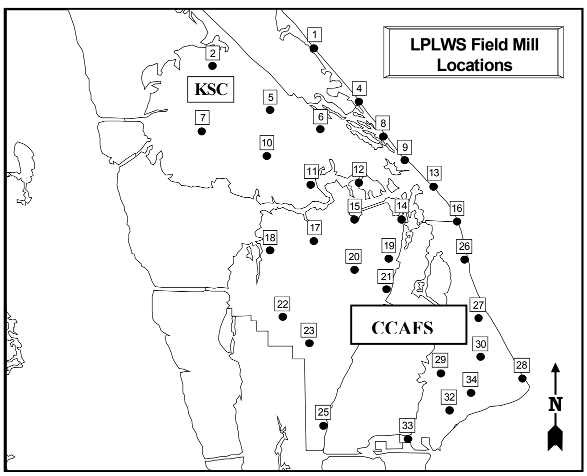

Figure 2. Field Mill Locations

The Cloud-to-Ground Lightning Surveillance System (CGLSS) was first installed with three test sensors prior to the first Shuttle launch in 1981. Over the past twenty years, the system has undergone many improvements. The network is currently a short-baseline 6-antenna magnetic direction-finding/time-of-arrival IMPACT (Improved Accuracy from Combined Technology) system. The CGLSS is deployed in and around the launch and operations area on relatively short baselines and operates at low gain to ensure the requirements for high locating accuracy and detection efficiency are satisfied. This arrangement limits the CGLSS effective range to about 100 km.

Data from the National Lightning Detection Network was added in the early 90's to satisfy lightning detection requirements beyond 100 km. The NLDN is a long baseline mix of high gain MDFs and time of arrival (TOA) sensors operated as a commercial service by Global Atmospherics, Inc. Sensor data are collected and processed in real-time at a network control center in Tucson, Arizona and then processed data are broadcast to subscriber locations using a dedicated satellite link.

The Lightning Detection and Ranging (LDAR) system consists of a network of seven time-of-arrival radio antenna receiver sites, which provides a three-dimensional depiction of the lightning, including: in-cloud, cloud-to-cloud, cloud-to-air, and cloud-to-ground lightning. LDAR was developed, and is operated and maintained, by KSC. The 45 WS receives and evaluates the data 24 hours per day, 7 days per week.

3.2 Upper-Air Systems

The current ER upper-air system, described by Wilfong et al. (1996), is operated and maintained at CCAFS by the RTS Contractor. The Meteorological Sounding System (MSS) was originally accepted on the ER in 1982. The frequency of upper-air observations varies from two or three (transponder) rawinsondes per day (for routine forecasting needs), to a combination of 16 or more (rawinsondes and Jimspheres) in 24 hours to support a single launch. The added observations are needed to satisfy the complete weather requirements for direct support to Range Safety and launch customers. The upper-air observation requirements are very demanding during every launch countdown to serve the many customers (forecasting, safety, steering, and loads) as described by Boyd et al. (1997). Range Safety requirements most often are encompassed by those of other users. As an example of upper-air measurements taken during a launch countdown, Table 4 depicts the balloon release schedule for a typical Shuttle mission. Dynamic weather conditions and other items such as accident probability or potential severity often require additional balloon releases to support Range Safety or the launch customer.

Table 4

Typical Shuttle Upper-Air Schedule (Time is hours relative to launch and height is in thousands of feet)

Time	Type	Height (feet)
L-36	rawinsonde	100K
L-28	Jimsphere	55K
L-24	rawinsonde	100K
L-13	rawinsonde	70K
L-8.5	rawinsonde	100K
L-6.75	Jimsphere	55K
L-5.5	rawinsonde	70K
L-4.25	Jimsphere	55K
L-3.5	rawinsonde	50K
L-3	Jimsphere	55K
L-2	rawinsonde	55K
L-2	Jimsphere	55K
L-1.5	rawinsonde	20K
L-1.17	Jimsphere	55K
L-1	rawinsonde	10K
L-0.5	rawinsonde	100K
L+0.25	Jimsphere	55K

The radar-tracked Jimsphere combined with the ROSE (Rising Observational SpherE) program has evolved as the primary system for making high-resolution wind profile measurements in support of the Space Shuttle and other launches for vehicle structural design limitations. However, both NASA and Range Safety require more complete upper-air data: temperature, humidity, pressure, and winds; as provided by rawinsondes. To provide Range Safety their required data, the ER uses transceiver sondes, which are tracked and processed by the MSS to provide upper-level parameters required by Range Safety.

Evaluation of radar wind profilers to directly improve structural stress analysis support started at the ER in 1987, when NASA awarded a contract to design and build a demonstration super-profiler system to be installed next to the Shuttle Landing Facility at KSC (Smith, 1989). The NASA/KSC Doppler Radar Wind Profiler (DRWP), commonly referred to as the 50 MHz DRWP, operates at 49.25 MHz with an average power-aperture of 10^8 Wm^2 and measures winds from 2 to 18.6 km once every five minutes. A wide range of parameter settings provides flexibility in the radar operating characteristics. Data from the NASA/KSC DRWP currently do not enter into stress calculations for the Shuttle, but the Shuttle, Atlas, Delta, and Titan programs use the profiler data to monitor wind changes on the day of launch. A significant change may delay the launch until another Jimsphere can be released and data analyzed (Wilfong, et al., 1996).

A contract was awarded July 1996 to replace the current upper-air system at both the Western and Eastern Ranges with an Automated Meteorological Profiling System (AMPS). Full Range (Eastern and Western) acceptance of the system is expected in 2002. The AMPS will use differential GPS-based technology for computing upper-level wind speed and direction. The low-resolution mode will provide geometric altitude (MSL), horizontal winds, air temperature, pressure, and relative humidity from the surface to a minimum of 100,000 feet, with an effective vertical resolution of 1,200 feet, or better. The high-resolution mode will provide geometric altitude and horizontal winds from the surface to a minimum of 55,000 feet, with an effective vertical resolution of 400 feet, or better (Harms et al., 1998).

3.3 Boundary Layer Sensors

Boundary layer sensing at the ER is accomplished by two major systems: a network of 44 meteorological towers with wind, temperature, and dew point sensors at various levels and a network of five 915 MHz DRWPs with Radio Acoustic Sounding Systems (RASS). Most towers are 16 to 18 m tall, with sensors at two levels. Three others are 67 m and one is 165 m with sensors at various heights. All report wind, temperature, and dew point, either each minute or every five minutes. The towers are organized into three different groups: (1) launch critical, (2) safety critical, and (3) forecast critical. The application determines the sensor complement on the tower, how the base station interrogates the tower, and how the data are processed and displayed at the base station. All data are processed and displayed as an integrated network and any tower can contribute to any application.

To fill the data gap from the top of the wind towers to the lowest gate of the 50 MHz DRWP, the ER started a project in May 1992 to procure and install a network of 915 MHz boundary layer profilers with RASSs (Madura, et al., 1991, Lucci, et al., 1998). The system has undergone testing and modification over the past eight years. When accepted on the Range, this network will sample low level winds from 120 m to 3 km every 10 minutes and produce virtual temperature profiles every 15 minutes, greatly enhancing the forecasters' ability to track the sea breeze convergence zone. It will also produce near real-time winds for use in emergency toxic dispersion calculations and improve meteorological data input to the safety models. The network is arranged in a diamond-like pattern over the area with an average spacing of 10 to 15 km. These radar wind profilers, when fully operational, offer the potential to greatly reduce the number of balloons released (Harms et al., 1998).

3.4 Weather Radar

In 1983, the ER purchased and installed a WSR-74C (5-cm wavelength) weather radar to replace the FPS-77. A project was immediately started to incorporate a volume scan processor to produce data sets from 24 elevation angles between 0.6 and 35.9 degrees sampled over five minute intervals. In 1987, the volume scan project was completed, with the WSR-74C radar control and display consoles (one for the Applied Meteorology Unit (AMU) and one for Range Weather Operations (RWO) located at CCAFS, with the transmitter/receiver antenna located at Patrick Air Force Base (Austin, et al., 1988). Data digitization allowed forecasters to construct and display Constant Altitude Plan Position Indicator (CAPPI), vertical cross-sections, and echo tops, animate displays, and extract point information such as maximum tops and radial location. In 1996, a project was initiated to increase the rate of data sets to every two and a half minutes. That project was completed in 1998 (Boyd et al., 1999). The volume scan strategies were further refined over the next two years to better support operations (Short, et al., 2000).

The third (of the first five nationally procured) "NEXRAD" was installed in Melbourne in 1989. The ER has direct access to that National Weather Service WSR-88D via three Principal User Processors (PUPs); one each located at the RWO and AMU at CCAFS, and one at the Patrick AFB weather station.

3.5 Satellite and Display Systems

The current satellite processing and display system, the Meteorological Interactive Data Display System (MIDDS), was installed in 1984/85 and was first described by Erickson et al. (1985). Over the years, it has undergone many modifications but today is still a derivative of the University of Wisconsin Space Science and Engineering Center's (SSEC) Man-computer Interactive Data Access System (McIDAS). The original goal of MIDDS was to consolidate all meteorological data (from over 900 pieces of meteorological equipment and two dozen systems) into a single data management and display system. Although that goal has yet to be fully reached, it remains valid today.

While many ER systems input data to MIDDS, the most critical interface is for the direct local reception of GOES meteorological spacecraft data. Two independent antenna and receive systems permit simultaneous reception from the nominal complement of the GOES east and the GOES west spacecraft.

4. WEATHER DATA DISSEMINATION

The 45 WS uses a Launch Weather Team (LWT) to monitor, forecast, and evaluate all weather constraints during a launch. That LWT disseminates (to launch decision authorities) weather information, which can be critical for "GO/NO-GO" launch decisions. The LWT members usually include: Lead Launch Weather Officer (LWO), Deputy LWO For Radar And Lightning Systems, Deputy LWO For Weather Reconnaissance Aircraft, Flight Commander of Range Weather Operations, and Mission Support Commander (the 45 WS Commander, or Director of Operations). Weather constraints consist of the standard "Range Safety Constraints for the Avoidance of Natural and Triggered Lightning", as well as "User" constraints such as temperature, precipitation, and wind. The LWT must have clear and convincing evidence, and unanimous consensus, that the LCC are not violated. LCC status is referred to as "RED", violated, or "GREEN", non-violated. The LWT is required to analyze data from the numerous and diverse weather sensors used by the 45 WS, as well as special airborne weather reconnaissance cloud observations, and may be required to evaluate the complex LCC under rapidly changing, threatening weather. If any constraint is violated, "RED", the LWO rapidly relays that status to the Flight Control Officer, via voice communications, who takes appropriate action. The LWT thus provides a simple " "RED" or "GREEN" to the Launch Decision Authority. However, the LWT can display the weather data on Closed Circuit Television (CCTV) so the Launch Director has a better understanding of the actual weather situation.

A Lead LWO is assigned to each launch vehicle program to specialize in their weather requirements and to serve as the single weather voice to that launch vehicle program. Scheduled, as well as on-demand, briefings and displays are presented via CCTV and voice communication networks. Displays include graphical displays of data from local sensors, such as mesonet towers, lightning detection equipment output, as well as the more standard meteorological information such as satellite and radar. Visual displays of LCC status, and text forecasts are also provided.

Throughout the countdown, critical time sensitive upper-air data are measured, quality controlled and provided to each customer, who assesses the impact to their launch vehicle. A stress analysis is completed by the customer and data up-linked to the launch vehicle. Quality controlled DRWP wind data is also relayed to the customer via MIDDS and/or dedicated communication lines. The DRWP data is processed by the user to determine if winds are still within acceptable limits. If analysis determines wind data are out of limits, the launch is held until balloon data can validate safe conditions.

National numerical weather model data (grids) are relayed by MIDDS to Range Safety. That data is in turn input to ER safety analysis models. Data from boundary layer and upper-air sensors are also input directly, or modified as "forecast data". Range Safety personnel then run models for toxic and blast overpressure to make an assessment call to the Launch Decision Authority regarding safety of both on-base and off-base personnel.

5. SUMMARY

With the help of many dedicated individuals in diverse organizations, the Air Force and NASA have established the world's premier instrumentation site for operational meteorology to support America's space program at the Eastern Range. The current challenge is to provide necessary information to the launch decision-makers in an accurate and timely fashion.

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