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JOHN F. KENNEDY SPACE CENTER
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ROCKET-TRIGGERED LIGHTNING STRIKES AND FOREST FIRE IGNITION

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Abstract

The report presents background information on the rocket-triggered lightning project at Kennedy Space Center (KSC), a summary of the forecasting problem there, the facilities and equipment available for undertaking field experiments at KSC, previous research activity performed, a description of the atmospheric science field laboratory near Mosquito Lagoon on the KSC complex, methods of data acquisition, and present results. New sources of data for the 1989 field experiment include measuring the electric field in the lower few thousand feet of the atmosphere by suspending field measuring devices below a tethered balloon. The report also details problems encountered during the 1989 field experiment, and lists future prospects for both triggered lightning and lightning-kindled forest fire research at KSC.

Summary

Kennedy Space Center (KSC) is the center for and its operations the focus of the world's most exacting single-point, short-range weather forecasting problems. Thunderstorms, with lightning, hail, strong winds, and possibly tornadoes, represent the greatest hazard at KSC.

The present Atmospheric Science Research Laboratory program at KSC includes ground and airborne electric field measuring instruments (field mills); a ground-based radar; numerical models; rocket triggered lightning experiments; and conventional, fairly dense network of reporting stations and rain gages. When available, KSC will add a high-resolution wind profiler now being developed at Marshall Space Flight Center.

KSC recognizes the critical nature of smaller scale weather phenomenon in the forecasting problem addressed, i.e. short-period, precise, local weather forecasts. No other group has ever attempted to forecast on a routine basis the weather events KSC desires to predict. KSC will first attempt to improve the general understanding of smaller scale weather phenomena. The research project coordinates actions of disparate groups in collecting and analyzing heterogeneous data, and in integrating results into a real-time data display system.

Some problem areas: Most of the individual research efforts by the various participating groups take place without coordination with either KSC or the other cooperating groups. KSC is trying to integrate the research program into a unified effort. Devising a reliable operational forecasting method may take many years and considerable effort from KSC, other government weather-forecasting units, and academia.

Work on lightning-kindled forest fires has just begun at KSC, and will continue.

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I

INTRODUCTION

1.1 BACKGROUND INFORMATION

The lightning program at Kennedy Space Center (KSC) began in the 1960's, when the National Aeronautics and Space Administration (NASA) began building taller structures on the Center. Lightning strikes to Apollo 12 and, more recently, to an Atlas-Centaur rocket, resulting in both its and its payload's destruction, gave rise to added research to understand lightning better. KSC used their own employees, as well as cooperated with academic institutions and private companies in developing its lightning program. The present program includes ground and airborne electric field measuring instruments (field mills), radar; numerical models, rocket triggered lightning experiments, and conventional mesometeorological network of reporting stations and raingages.

Most of the individual research efforts by the various participating groups take place without coordination with either KSC or the other cooperating groups. KSC needs to integrate the entire research program into a unified program. Moreover, KSC needs to use the results and techniques developed for its day-to-day operations. Additionally, the limited meteorological expertise at KSC has hampered the research effort, requiring KSC to rely heavily on outside personnel and equipment for this research.

Numerous disparate groups and organizations have some expertise in various aspects of thunderstorm and lightning phenomena. Railroads know about lightning's ability to travel long distances along rail tracks, and to cause damage far from the original strike. Electric power companies also know how lightning travels through its conductors to damage equipment far from the thunderstorm producing the lightning. They also know lightning can couple into lines not originally struck by lightning. Airlines and the military know lightning strikes aircraft both in the air and on the ground, and that aircraft can trigger lightning flashes even far from a thunderstorm cloud. Radio and television stations, as well as telephone companies know lightning strikes their towers and disrupts their transmissions and communications. It also couples into their equipment. Boaters, anglers, and golfers, among others, know their recreational equipment (rods, masts, golf clubs) may serve as conductors for lightning strikes--particularly newer graphite materials in rods, masts, and club shafts.

1.2 THE LIGHTNING FORECASTING PROBLEM AT KENNEDY SPACE CENTER

KSC is the center for and its operations the focus of the world's most critical single-point, short-range weather forecasting problems. Many operations at KSC are extremely vulnerable to weather, usually in such novel ways that the forecasting problem has no counterpart in any other realm. The forecaster must develop their own experience at KSC, they cannot rely on experience gained elsewhere to help them with unique KSC forecasting problems.

The special nature of weather at KSC, as well as extremely high economic and human costs if KSC launches (and therefore missions) fail leads to very precise forecasting criteria with extremely little margin for error. KSC success or failure also impacts directly and significantly on national and international opinion of United States' space effort and expertise. KSC failures draw considerable national and international attention! Thunderstorms, with lightning, hail, strong winds, and possibly tornadoes, represent the greatest hazard at KSC.

In its approach to forecasting extreme weather, KSC recognizes the critical nature of smaller scale weather features and phenomenon (mesoscale components) on the problem addressed: short-period, precise, local weather forecasts. Even the excellent world-wide weather data available through MIDDS cannot by itself make the local weather forecasting problem easier. KSC plans to integrate weather data from satellites, radar, its own local mesonetwork of weather stations, regional weather stations, and data on local lightning strike into the forecasting technique. When available, KSC will add a high-resolution wind profiler (now being developed at NASA Marshall Space Flight Center [MSFC]).

Other data for the weather forecasting scheme envisioned include dual-doppler radar, NEXTRAD at Melbourne, Florida; ground- and airborne electric field measurements from KSC-operated sites; and local lightning-locating data. If at all possible, KSC envisions using its rocket-triggered lightning data into an operational forecasting technique. Since no one, to our knowledge, has ever attempted to forecast on a routine basis the weather events KSC desires to predict, we can only describe the forecasting as experimental. Devising a reliable operational forecasting method may take many years and considerable effort from KSC, other government weather-forecasting units, and academia.

The approach KSC will take will first attempt to improve our understanding of smaller scale (mesoscale) weather phenomena. Only when we obtain an adequate knowledge of the systems we wish to forecast can we confidently try to predict that phenomenon. This approach requires, however, the close coordination and cooperation of disparate, heterogeneous data, and its integration into a real-time (preferably interactive) data display system. The forecasting problem will also almost require such a technique, because KSC must forecast weather events lasting less than one minute, thus requiring almost instantaneous data collection and display. This requirement may not be unique (airports would also like to have this capability), but the economic and political costs of delays and wrong decisions at KSC are much, much higher than anywhere else.

1.3 FACILITIES AND EQUIPMENT

1.3.1 ATMOSPHERIC SCIENCE FIELD LABORATORY (ASFL). Kennedy Space Center (KSC) lies in a region of the United States with one of the highest

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frequencies of thunderstorms and lightning activity. **Figure 1** shows the location of the ASFL and other sites used for the RTLP. KSC operations involve some stupendously expensive equipment (the Shuttle, satellites, and launch vehicles) subject to critical and exacting time schedules. At the same time, launch support equipment such as towers, antennae, above ground and buried cable, are subject to damage or interruption of their function and use from lightning strikes. This combination of conditions make lightning both a hazard to and a significant factor in success or failure of KSC operations. As a result, KSC has been involved in and conducted extensive lightning studies for more than two decades. These studies involved characterizing lightning flashes, devising methods of protecting equipment from lightning strikes, and ways to locate and predict lightning and thunderstorms. Since the early 1980's, KSC, in conjunction with other Government organizations, private companies, and universities, has intensified its studies of thunderstorm and lightning phenomena.

KSC and the Eastern Space Missile Center (ESMC) weather group delve into thunderstorm and lightning forecasting, as well as devising methods of predicting other significant, adverse, or severe weather events (e.g. freezing precipitation, for, icing, or strong or gusty winds). The combination of KSC and ESMC have developed one of the finest facilities for forecasting short-range weather events. The KSC/-ESMC facilities include weather satellite and radar data, a mesoscale weather observation network (more than fifty stations), and the Meteorological Interactive Data Display System (MIDDS) which supplies world-wide meteorological data and soundings. The KSC also uses a tethered balloon for research on thunderstorms and lightning, and may be able to include this in future forecasting techniques.

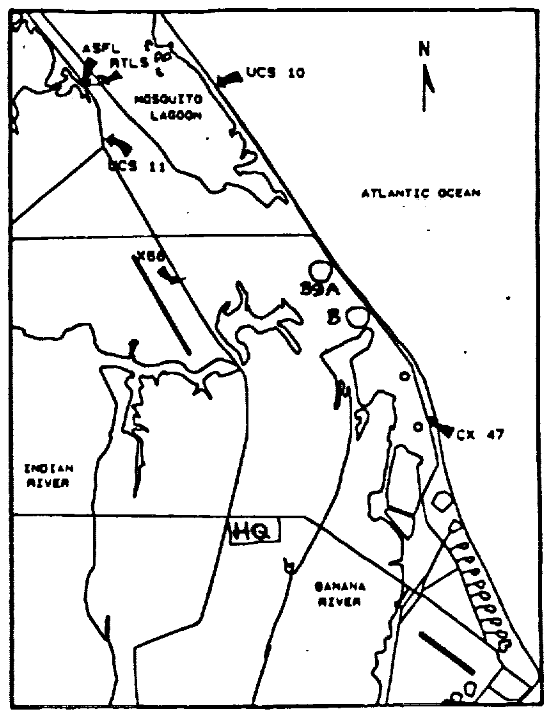

FIGURE 1-1 SITE LOCATIONS

KSC and ESMC wish to create and operate an advanced weather support and forecasting system in order to reduce weather-related hindrances to KSC operations. The KSC program also plans to transfer to other weather forecasting units (such as the US Air Force or the National Weather Service) the technology and knowledge gained through this research.

The Federal Aviation Authority (FAA), Air Force Wright Aeronautical Laboratories (AFWAL), and the US Naval Research Laboratory (NRL) are among the Government groups interested in lightning studies at KSC. KSC and other groups are interested in (1) characterization of lightning hazards to KSC operations, to communications, to power distribution, and to command and control systems; (2) remote lightning detection; and (3) understanding the "advent and demise" of thunderstorms. In addition, certain groups within the Government are interested in using lightning strikes to simulate the electromagnetic pulse (EMP) nuclear weapon bursts might send out.

After learning more about lighting and its effects on air- and spacecraft, KSC would like to transfer the techniques and knowledge gained from its studies to operational forecasting and to academic institutions training weather forecasters. This should ensure qualified forecasters for future operations.

1.4 DATA ACQUISITION

Items investigated in KSC lightning and thunderstorm studies include static and field charges using electric field measurements in and around KSC; locating and counting lightning discharges (cloud-to-ground strikes, mainly) within 200 miles of KSC; radar data from the KSC region; surface wind data using a mesoscale network of measuring stations within about 50 miles of KSC; electric and magnetic fields and lightning current measurements from the KSC area; and other meteorological data obtained from local, regional, and national sources. These data will, hopefully, be integrated into a forecasting method and applied to improving short-term weather forecasting and verification of numerical weather forecasting, and to evaluating lightning warning procedures.

The Maxwell current and its changes with time may help researchers understand when thunderstorms begin ("turn on") and when they quit ("turn off"). Maxwell current may thus ultimately lead to an approximate threshold for impending lightning strikes. (Lightning and its accompanying thunder define a thunderstorm; without these two phenomena, the event is merely a rain- or hailshower.)

Photo analysis of lightning by the State University of New York at Albany (SUNYA) may be used to quantify several parameters, such as size and shape of strokes. Streak images yield stroke propagation speed.

The program at KSC is the first program to measure all parameters (electric and magnetic field, current, electron temperature in the lightning plasma, luminosity, spatial orientation, and stroke propagation speed) at the same time, thus allowing case studies to test theoretical and numerical models of lightning behavior.

Photography on calibrated film can determine flash luminosity. If luminosity is a function of current, then we can measure lightning current directly. Further, time resolved lightning spectra would then yield electron temperature in the lightning channel. Photographic images can be analyzed by video densitometers, if digitized, or conventional densitometers if not.

Kennedy Space Center (KSC) receives wind observations from a network of over 50 instrumented towers covering an area about 53 by 57 km (about 1600 square kilometers) as shown in figure 1-2. Most wind instruments have been mounted on top of standard 54-foot tall telephone poles, and set to record wind data at five-minute intervals.

Three direction-finding stations locate negative lightning flashes (where earth is positive relative to cloud). Lopez and Holle (1986) describe the lightning direction-finding method.

A United States Air Force WSR-74C radar located at Patrick AFB, approximately 30 km SSE of KSC, supplies data at five-minute intervals. A Weather Bureau radar at Daytona Beach, about 100 km NNW of KSC, also supplies radar imagery at irregular intervals. A Lightning Location and Protection, Inc, (LLP) Integrated Storm Information System (ISIS) records negative lightning flash information as well as Daytona Beach radar information. This ISIS equipment is currently located at the US Fish and Wildlife headquarters on KSC property, but KSC plans to move it to their Range Control building on Cape Canaveral Air Force Station during July.

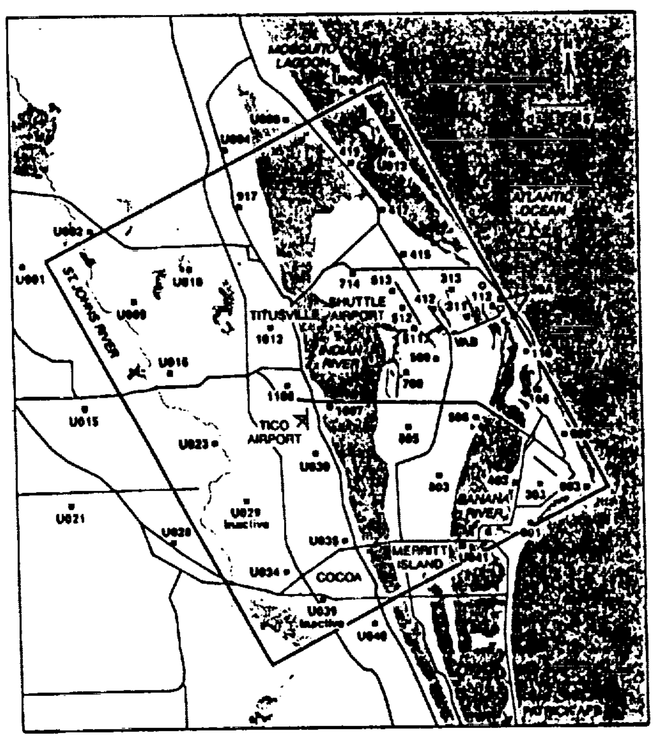

Fig. 1-2 Kennedy Space Center and Cape Canaveral Air Force Station area. The rectangle marks the 1989 mesoscale network. Solid squares indicate meteorological stations. Patrick AFB (lower right) is the site of the USAF WSR-74C weather radar. (After Watson, et al.)

Lightning triggered when small rockets trailing a conductive wire behind them (rocket-triggered lightning, RTL) are launched near active thunderstorms provide several advantages for scientific study of lightning. First, lightning occurs at a pre-defined place and at a pre-determined time. This allows researchers to measure parameters seldom--and then only with extreme difficulty--measured in the natural atmosphere. Secondly, it allows a detailed look at the very long "leader" strikes propagating into un-ionized air, close to the conditions prevailing in an unmodified environment. Both of these advantages help researchers understanding lightning leaders, thus understand lightning itself better--and, more importantly, that triggered by aerospace vehicles traversing that region of the atmosphere.

Suspending an isolated metallic object (a cylinder about eight feet long and two feet in diameter) below a tethered balloon as a lightning strike object (LSO) may also simulate an aerospace vehicle-triggered lightning (ATL) object. Leaders observed and measured during such strikes will provide data for comparison with prior observations, hopefully to verify or refute the bi-directional ATL model commonly proposed. The series of field mills suspended along the tether cable provides electric field measurements around the LSO. This experimental set-up also allows negative leader current to be measured at the LSO site, possibly permitting return-stroke current measurements at ground and higher levels at the same time. Streak cameras and conventional photography record visual imagery for later quantitative study.

Data taken both over land and over water allows similarities and differences to be observed and measured. Rocket launches over water represent a "purer" electric lightning signature, since there is no distortion of the signal from the ground or support equipment around the launch pad. The 1989 RTLP includes launches from land and water RTLS; my proposal is to launch from each site alternately, or from each at short intervals, i.e. quasi-simultaneously.

Other sensors include microphones to record the sound of thunder; and current sensors in the ground (correlated with negative cloud-ground potential.)

PRESENT RESULTS

2.1 NEW METHODS OF DATA ACQUISITION

The 1989 rocket-triggered lightning strike research season envisions recording positive lightning strike data as well as negative. The State University of New York at Albany (SUNYA) plan to operate a system using satellite data to provide actual lightning strike location data.

KSC will also attach electric field measuring instruments ("Field mills") at intervals along the cable attached to a tethered balloon located near the rocket launch site. This will supply a vertical sounding of electric field strength near the triggering site, important data presently missing. Six field mills located along the tethering cable will supply field strength at heights of approximately 300, 400, 500, 600, 700, and 800 m above the ground.

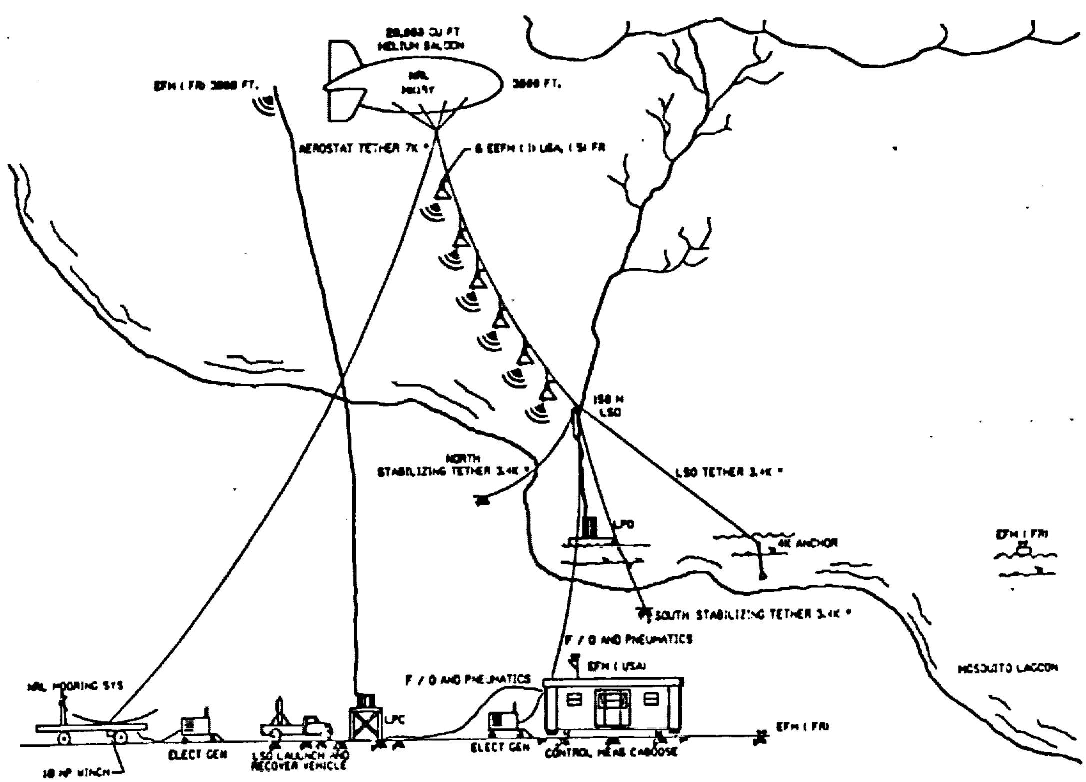

Fig. 2-1 1989 RTLP

2.2 RESULTS FROM 1989 FIELD EXPERIMENT

2.2.1 PROBLEMS WITH EQUIPMENT. Prior to beginning the 1989 field experiment at the RTLS and ASFL, KSC encountered several unexpected problems. These problems delayed the field experiments; consequently, the RTLP gathered little data prior to my departure. This report thus presents few results, and those only preliminary.

The 1988 field experiment ended August 31, 1988. From that date until just before my arrival June 12, 1989, the ASFL and RTLS buildings, as well as all equipment, sat idle. Preliminary inspection by my KSC colleague, Mr. Bill Jafferis, indicated some equipment needed service and calibration. Unfortunately, before KSC could accomplish this calibration and service, the fire marshal and building inspectors noticed a number of safety discrepancies. These discrepancies required immediate repair; they also precluded service to and calibration of equipment housed in those buildings until the buildings themselves had been fixed.

Adding to the delayed caused by building troubles, the tethered balloon leaked. It, too, required repair. However, since the much larger balloon, "Fat Albert," came down for patching the week I arrived, its repair delayed all repairs to the RTLP balloon. Further, one tether cable apparently needed to be replaced; a new cable required about five weeks for delivery. As of August 1st, the tethered balloon has not been flown. As a result, no airborne field mills supply data, because they have not yet been launched.

Another problem surfaced on June 25th, when the thunderstorm and lightning display system, ISIS, ceased receiving radar data from the Daytona Beach radar. Replacing the modem and other attempts to find and fix the problem failed. As of July 26th, ISIS is still not receiving a radar signal, even though the signal appears to be arriving at the site. The ISIS does record lightning strike location, which is useful, but lack of associated radar returns used to deduce the physical relationship between the lightning and the parent thunderstorm limit ISIS's value as a forecasting tool.

Since all attempts to find and correct the problems with ISIS failed, and we knew the telephone lines on the northern parts of KSC are not as good as those elsewhere, we decided to move the system. KSC personnel and I moved the ISIS from its previous location at the headquarters building of US Fish and Wildlife service, about ten miles north of the main KSC complex of buildings, to the Range Control building on Cape Canaveral Air Force Station. Unfortunately, trouble with the central computer in that building have thus far (Aug 1) prevented use of the ISIS at that location, too.

If these problems were insufficient to delay the start of the 1989 field experiment, others followed: The French researchers from Grenoble delayed their arrival by about ten days. Since they actually run the RTLS, launch the triggering rockets, and gather data, their delay pushed the start of operational rocket launches back still more. Moreover, even after they arrived in the middle of July, their equipment failed to arrive for another several days.

All RTLP equipment and personnel appeared to be ready for the first rocket launch only on July 21st. Unfortunately, for a number of days thereafter, weather conditions did not produce lightning at the launch site on Mosquito Lagoon. The first operational launch occurred on July 29th, but only one rocket was launched. The remainder of the day, we waited in vain for fields to build up to launch criteria (about 4500 V/m.)

2.2.2 SOME PRELIMINARY RESULTS FROM THE 1989 FIELD EXPERIMENT. Due to delays outlined above, coupled with my departure August 4th, this report gives only a few preliminary results from the 1989 field experiment.

Table 2-1, next page, gives a small sample of the lighting-strike data recorded and archived for the project. Table 2.1 gives azimuth (direction in degrees from true north) and range (in nautical miles) relative to the recording site. On this day, July 29, 1989 (Julian date 89210), about 1000 cloud-to-ground lightning strikes occurred within 25 nautical miles of the recording location on Cape Canaveral AFS. Table 2.1 lists only the first few strikes recorded. Time is given in hours, minutes, and seconds Universal Time (or Greenwich Mean Time).

Table 2-2, next page, provides a small sample of the wind data. Wind measuring equipment is generally mounted on top of telephone poles of varying lengths; thus, the heights range from about 45 to 65 ft, with a mean of 54. Some locations also record temperature and dew point in Kelvin, from which we derive relative humidity. Average wind speed and maximum wind gust recorded during the previous five minutes are given meters per second. Figure 1-2 shows the location of each station.

2.3 LIGHTNING-KINDLED FIRES IN FOREST PRODUCTS

The plan was to place piles of toothpicks, kindling sawn from 1/4-inch plywood, 1-by-1's, and 2-by-2's at the launch site to see which ones ignite. KSC also intends to measure the current in each strike. The idea of using well defined sizes of wood is to achieve reproducible results. Again, no results have been obtained due to paucity of triggered lightning.

Table 2-1. Sample Lightning Data for July 29, 1989

THE FOLLOWING INFORMATION DEPICTS LIGHTNING OCCURRING WITHIN 25NM OF THE RCC AND COMPLEX 1/2

DAY	TIME	AZIMUTH	RANGE (n.mi.)
89210	20405	235°	20.9005
89210	20539	233	22.6031
89210	20539	224	18.7438
89210	20753	235	21.5042
89210	20902	231	23.5604
89210	21057	237	20.9962
89210	43814	333	24.9781
89210	51134	330	22.1674
89210	60032	332	21.9072
89210	65848	339	15.3245
89210	71953	326	14.6215
89210	75912	329	20.9053
89210	183951	204	14.64
89210	184107	191	17.6217
89210	184159	206	18.0055
89210	184237	192	18.4356
89210	184301	191	16.9742
89210	184334	196	18.7138
89210	184458	190	17.8074
89210	185058	310	15.7288

Table 2-2. Sample Wind Data for July 29, 1989

				W	I N	D			
Day	Time	Site	Ht	Dir	Speed	Gust	Temp	Dew Pt	RH
89210	235500	1	54	167	3.0	3.6	300.38		
89210	235500	3	54	213	4.1	4.6	300.38		
89210	235500	5	54	183	3.6	4.6	301.49	300.77	96.0
89210	235500	108	54	178	2.5	3.6	299.82		
89210	235500	110	54	188	3.0	4.6	300.93	296.54	77.0
89210	235500	112	54	190	2.5	3.6	299.27		
89210	235500	303	54	189	2.5	3.0	298.71		
89210	235500	311	54	203	3.6	4.1	298.71		
89210	235500	313	54	198	2.0	2.5	299.82	295.93	79.3
89210	235500	403	54	182	2.5	3.0	299.27		
89210	235500	412	54	199	2.0	2.5	298.71		
89210	235500	415	54	186	2.5	3.0	298.71		
89210	235500	506	54	195	3.0	3.6	299.82		
89210	235500	509	54	206	2.0	2.5	298.16		
89210	235500	714	54	165	3.0	3.0	299.27		
89210	235500	803	54	166	1.5	1.5	297.04		
89210	235500	419	65	7	1.0	4.1			
89210	235500	417	60	175	1.5	2.0			
89210	235500	1007	42	185	2.5	3.0			
89210	235500	709	44	185	1.5	2.0			
89210	235500	805	54	62	1.5	2.0			
89210	235500	917	45	0	0.0	0.0			
89210	235500	1012	48	173	0.5	1.0			
89210	235500	1108	47	32	1.0	10.8			
89210	235500	39	60	219	4.6	5.6	299.27		
89210	235500	39	60	202	4.1	4.6	299.27	294.93	77.0

III

CONCLUDING REMARKS

3.1 NEW DEVELOPMENTS AND PROPOSED METHODS FOR FORECASTING LIGHTNING

The current system for forecasting thunderstorm location and lightning strike location uses a composite technique including maximum radar reflectivity of thunderstorm cells; location, number, and frequency of negative lightning strikes; surface wind convergence; and surface wind pattern. (Surface wind pattern typically varies with stage of thunderstorm development. See Byers and Braham [1949] or Watson et al. [1989])

As Shuttle, and other, launches become scheduled more frequently, KSC operations less tolerant of delays. Thus, KSC forecasters need to identify more low-risk launch window, requiring improved forecasting of weather events such as triggered lightning, wind shear, and turbulence with accuracy and timeliness unique to space programs. Measurements of electric fields, for example, have not yet been included in the forecasting process for triggered lightning. Moreover, many critical weather factors cannot even be measured directly; the forecasters infer their value from their relationship to other parameters they can measure.

Launch safety needs both accurate current weather data and forecasts for two hours or less. Observations limit the accuracy and quality of forecasts, particularly on this short-term forecasting, or nowcasting, time scale. KSC must improve its observations, including new instrumentation and measuring systems, to improve operational forecasts.

New instrumentation is no panacea, however. New instruments improve detection, not necessarily forecasting. Forecasting methods use the data available when those methods were developed. KSC needs to modify forecasting methods and techniques to include new data sources. Displays for lightning detection networks and new instruments to detect in-cloud and cloud-to-cloud lightning, for example, should be incorporated into KSC weather forecasting. Likewise, local weather analysis and forecasting techniques specific to KSC need to be developed. KSC should also develop an interactive, computer-aided weather decision-making system, and possibly numerical weather prediction models specific to KSC operations.

Local convergence of surface winds still induce thunderstorm formation at KSC. Byers and Rodebush (1948) and Byers and Braham (1949) suggested this cause, and many later experiments and studies supported them. The comparatively dense network of surface wind measurements at KSC allow use of local convergence for short-period forecasting. In particular, the forecaster must locate and follow the movements of the sea breeze, as it dominates all other convergence forces in and around KSC. A proposed, new prediction method (not yet completed) is to write computer programs to calculate and plot convergence over several sub-areas within the KSC research area (fig.I-2), and to locate lines and regions of convergence within the same area. Breaking the

KSC research area down into four or nine smaller regions, or sub-areas, should be adequate. Watson and Blanchard (1984) noted that smaller areas provide reasonably good predictions of thunderstorm development using average convergence data, but Watson et al. (1989) noted that larger ones do not, since the averaging process dilutes the convergence (large on a small scale) when averaged over an area as large as the KSC research area. My proposal to break the KSC area down into smaller units for automatic convergence computation would solve the apparent dilution problem.

Surface convergence does not, of course, take into account any dynamic processes occurring higher in the atmosphere. The MIDDS provides upper-level information. By writing programs to analyze and plot various combinations of data (the best combinations have yet to be determined), the forecaster should be able to predict at least the potential for triggered lightning. One thing the previous research at KSC has shown: Lightning appears to begin just after maximum convergence (averaged over a fairly small area), to peak before average divergence over the same area reaches a maximum, and to decrease as divergence decreases.

3.2 FUTURE PROSPECTS

From its start seven years ago on the shores of Merritt Island's Mosquito Lagoon, about eight miles north of KSC's Vehicle Assembly Building, NASA's Rocket-Triggered Lightning Program (RTLP) has developed progressively into a formidable research effort. NASA's desire to improve KSC lightning protection and lightning forecasting gave the RTLP emphasis. Each year adds new features to improve scientific knowledge. 1988 added a tethered balloon.

New elements added in 1989 included field mills suspended below the tethered balloon (at various heights above the ground), and attempts at quantifying lightning-initiated kindling of forest materials. Placing field mills at intervals between the ground and the height of the balloon (about 500 m) provides data on change of electric field strength with altitude, the better to help characterize lightning strike potential over land and water. Field mills detect and help locate lightning, as well as allow study of the electric field environment prior to lightning strikes. The series of field mills suspended below the tethered balloon provide a more complete view of weather conditions conducive to rocket- or aircraft-triggered lightning.

The future thrust should be in combining and assimilating the many diverse data sources into an integrated short-term predictive technique. One main thrust should lie in setting up an expert system or knowledge bank, a "forecaster's helper" along the lines of the artificial-intelligence based "doctor's associate" used by some physicians and in some hospitals. A second main effort, writing programs to analyze the myriad data sources (KSC local wind fields, electric fields, radar, and other data from MIDDS) automatically, should support development of an expert system. KSC apparently recognizes the fact that too little work has been done in integrating the excellent data, IV

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Acronyms and Abbreviations

AFWAL - Air Force Wright Aeronautical Laboratories

ASFL - Atmospheric Science Field Laboratory
Building near Mosquito Lagoon, about 15 miles north of the main KSC building complex, housing equipment, research space, and offices for conducting field experiments in lightning and other aspects of atmospheric science.

EMP - Electromagnetic Pulse
Pulse of electromagnetic radiation emitted by nuclear explosions.

ESMC - Eastern Space Missile Center

FAA - Federal Aviation Administration

ISIS - Integrated Storm Information System
System for storage and display of digital radar data and/or cloud-to-ground lightning strike location. Displays either radar or lightning data separately on the video terminal, or both together.

KSC - Kennedy Space Center

LLP - Lightning Location and Protection, Inc
Manufactures of ISIS.

MSFC - Marshall Space Flight Center

MIDDS - Meteorological Interactive Data Display System
World-wide weather data dissemination and display system.

NASA - National Aeronautics and Space Administration

NRL - Naval Research Laboratories

RTLP - Rocket Triggered Lightning Program
Program at KSC to launch small rockets into thunderstorm clouds, triggering lightning at the launch site.

RTLS - Rocket Triggered Launch Site
Site on Mosquito Lagoon, near the ASFL, where RTLP personnel launch small rockets into active thunderstorm clouds. Contains launch sites over land and water.

SUNYA - State University of New York at Albany