NASA Weather Support 2017

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Spaceport Integration and Services, SI-I3

October 2017

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Abstract

In the mid to late 1980's, as NASA was studying ways to improve weather forecasting capabilities to reduce excessive weather launch delays and to reduce excessive weather Launch Commit Criteria (LCC) waivers, the Challenger Accident occurred and the AC-67 Mishap occurred.[1] NASA and USAF weather personnel had advance knowledge of extremely high levels of weather hazards that ultimately caused or contributed to both of these accidents. In both cases, key knowledge of the risks posed by violations of weather LCC was not in the possession of final decision makers on the launch teams. In addition to convening the mishap boards for these two lost missions, NASA convened expert meteorological boards focusing on weather support. These meteorological boards recommended the development of a dedicated organization with the highest levels of weather expertise and influence to support all of American spaceflight. NASA immediately established the Weather Support Office (WSO) in the Office of Space Flight (OSF), and in coordination with the United Stated Air Force (USAF), initiated an overhaul of the organization and an improvement in technology used for weather support as recommended. Soon after, the USAF established a senior civilian Launch Weather Officer (LWO) position to provide meteorological support and continuity of weather expertise and knowledge over time. The Applied Meteorology Unit (AMU) was established by NASA, USAF, and the National Weather Service to support initiatives to place new tools and methods into an operational status. At the end of the Shuttle Program, after several weather office reorganizations, the WSO function had been assigned to a weather branch at Kennedy Space Center (KSC). This branch was dismantled in steps due to further reorganization, loss of key personnel, and loss of budget line authority. NASA is facing the loss of sufficient expertise and leadership required to provide current levels of weather support. The recommendation proposed herein is to re-establish the WSO under a high level office, with funding set at about the same levels as today, with a revitalized charter and focus to allow for the WSO to operate as originally intended.

History

The primary weather hazards to launch are low level winds, upper level winds, precipitation, temperature, natural lightning, and triggered lightning. In the absence of detailed knowledge of the level of hazards present, space flight weather decisions are by necessity conservative, which can lead to lack of launch availability. Since NASA has been established, it has steadily increased weather forecasting capability and has improved weather observational tools in order to increase launch weather availability and to maintain launch weather safety.

In the 1960's, as NASA launch rates steadily rose, ground instrumentation, local forecasting and launch commit criteria were enhanced to ensure the best possible weather support for launch. By the time of the Apollo XII launch in 1969, NASA and the USAF had installed natural lightning detectors and multiple weather stations on KSC and Cape Canaveral Air Force Station (CCAFS) property in order to avoid weather hazards while maintaining launch availability. After the Apollo XII launch vehicle triggered lightning on launch (1969), corrective actions were taken in February 1970 to add new Lightning Launch Commit Criteria (LLCC) to prevent recurrence. These Apollo XII corrective actions significantly reduced launch availability in order to increase flight safety.

With the introduction of the Space Shuttle, more formally named the National Space Transportation System (NSTS), NASA had a flagship vehicle with extreme sensitivity to weather. By the mid-1980's, the Shuttle launch team was processing on average two waivers to weather requirements for each launch, and was still experiencing a high weather-related launch delay rate. The weather observation instrumentation and LLCC for NSTS were upgraded as new technology became mature.

In the same time period, the Expendable Launch Vehicle (ELV) community continued to rely on the initial LLCC developed immediately after Apollo XII. Atlas Centaur (AC) 38 (likely struck by triggered lightning) illustrates a close call with the near catastrophic consequences (later realized in the destruction of AC-67) that can result from using faulty LLCC or faulty implementation procedures.[2]

In the fall of 1985, the OSF at NASA HQ established a Space Shuttle Weather Advisory Panel (chaired by John Theon) to review the weather support program and to develop recommendations to improve launch weather support coverage. The panel met for the first time in December 1985.

In January 1986, the Challenger accident occurred, with the main cause determined to be the failure of a Solid Rocket Booster (SRB) joint, caused in part by the very low temperatures experienced before blast-off and the consequent deterioration of the performance of the seal used in the joint.[3, 4] It has been argued that upper-wind conditions at launch time were a significant factor in the accident, in that severe turbulence may well have reopened a transient SRB metal seal.[3, 4] Upper wind conditions at KSC had been analyzed preceding to and at the time of launch showing that severely turbulent conditions were probable and that the conventional wind sounding system was inadequate for satisfactorily establishing the launch wind conditions.[3, 4]

In October 1986, the Theon Report was provided to the OSF. In that same month, responding to the Rogers Commission Report release in July 1986, the OSF sought the advice of the National Research Council (NRC) on how to ensure space flight weather support services were brought up to the "very state-of-the-art science and technology and are under an optimal management situation".[1]

In March 1987, AC-67 was launched into inclement weather conditions, in violation of Apollo era LLCC (older than the updated NSTS LLCC), and triggered a lightning strike to the vehicle which resulted in its total destruction. In August 1987, the Report of Atlas/Centaur-67 FLTSATCOM F-6 Investigation Board was released.

In August 1988, the NRC Report (Meteorological Support for Space Operations: Review and Recommendations) was released.

NASA and the USAF implemented the recommendations of these three reports pertinent to launch weather, and as a direct result there have been no weather induced launch failures in over 30 years.

- The Theon Report [5]
- The AC-67 Mishap Investigation Board Report [6]
- The NRC Report [1]

Only one of these reports was released strictly to reduce the likelihood of a mishap. The Theon Report and the NRC Report were focused on finding ways to increase knowledge and to improve decision making. Consequently, post AC-67, given similar weather conditions, NASA and USAF have increased launch weather safety while simultaneously improving launch availability.

The weather-related deficiencies and associated recommendations from these reports can be said to fall into five broad categories that were identified within the NRC report. Rephrased from the NRC report, here are the five major organizing functions of the modern weather support for space launch:

1. Quantification of weather hazards (creating data sets)
2. Observation system development and utilization (improving instrumentation)
3. Analysis, forecasting, and decision making
4. Organization and coordination of operations and research
5. Applied research, advancement in forecast tools and techniques

NASA and the USAF responded to the recommendations energetically. As a result, from 1987 onward, the weather support capability for American spaceflight improved in a spirit of collaboration between both American space programs.

In the late 1980s, the WSO was staffed by two senior NASA civilians and a senior military liaison officer from the USAF. Although the formal title was the Space Shuttle Headquarters Support Office/Weather Office, it was generally known as the Weather Support Office (WSO).

In the 1990's, both KSC and CCAFS were updated with an operational suite of specialized instrumentation systems and specialized local real time forecast tools to provide weather support for launch superior to any other location in the world. Over time, LCC have been revised in ways that would not have been possible without the upgrades and improvements made upon the recommendation of the meteorological board reports made in the late 1980's.

As part of a NASA cost-cutting reorganization in 1995, the agency-wide responsibility for weather support to the Shuttle program was transferred from the NASA Headquarters Weather Office, which was abolished, to the KSC Weather Office. The KSC Weather Office (KWO) assumed the WSO agency-wide responsibility to assure that weather support to NASA spaceflight missions and operations, manned or unmanned, was adequate.

As the shuttle program ended and NASA began to transition to the post-Shuttle era, the NASA wide influence of the KWO began to wane based on KSC local budgetary decisions. The autonomy previously established within the NSTS budget became subject to available funding streams obtained from KSC resident programs that previously had not been responsible to fund weather support.

The KSC Weather Office Chief retired and the KSC Weather Officer passed away in 2014. The KWO was reorganized along with the rest of the center, and due to budget cuts, the remaining three NASA weather office employees were required to assume duties previously performed by contractors to support the AMU. The office was disbanded and employees were assigned to a branch in the Spaceport Integration Directorate. At the beginning of 2017, the acting KSC Weather Officer retired.

As of October 2017, there are two full time NASA workers in the branch performing technical weather support duties and providing direct launch support. The weather budget authority and the weather staff's ability to influence weather support decisions are reduced with every budget cycle.

With the loss of the key WSO function, one of the five major organizing functions of weather support, "4. Organization and coordination of operations and research", can be considered as lapsed. The funding and the support for the other four weather support organizing functions are threatened due to the lack of an influential WSO to defend the utility of the capabilities.

The weather support organizing function to provide "5. Applied research, advancement in forecast tools and techniques", is embodied in the Applied Meteorology Unit (AMU). The AMU functions as a development test bed, but is not fully recognized within NASA as a key sustaining tool required to support all tailored local forecasts used by the operational USAF 45th Space Wing (45SW) Weather Squadron for all Eastern Test Range (ETR) launches. The operational local forecast tools also threatened by the loss of funding for the maintenance of the NASA data archive server and for NASA-provided data feeds of synoptic forecasts provided to the LWO. The NASA funding for the USAF 45SW Launch and Test Range System Integrated Support Contract (LISC) tasked with maintaining instrumentation on CCAFS and KSC is threatened with elimination. The current state of the implemented recommendations from the Agency meteorological boards that serve as the organizing functions for modern launch weather support follows:

1. Quantification of weather hazards (Budget threatened)
2. Observation system development and utilization (Budget threatened)

3. Analysis, forecasting, and decision making (Budget threatened)
4. Organization and coordination of operations and research (Lapsed)
5. Applied research, advancement in forecast tools and techniques (Budget threatened)

As far as forecast tools and observational tools and expert civilian forecast teams, weather support for launch is at an all-time high. However, with the loss of the WSO, NASA weather has diverged from the primary recommendation of the Theon Report:

> "The Panel's first and strongest recommendation was that the Shuttle weather support services must be organized in such a way as to bring them up to the very state of the science and technology and are under an optimal management situation. *Although equipment and software capabilities are important, the Panel felt that technical leadership, a competent and dedicated staff, their commitment to a long term of service to the NSTS team, and their visibility in the decision-making process were much more important considerations*."[5] (Emphasis added)

With loss of control of the weather support budget, funding support for NASA instrumentation is immediately threatened and funding support for the USAF 45SW LISC contract is expected to be withdrawn in the next few years. In 2019, with the anticipated retirement of one of the two NASA weather office workers, the organizational weather support framework will be reduced to levels far lower than those observed prior to when the Theon and NRC reports were issued, and NASA weather will see a further break in continuity. NASA KSC will lose the ability to sustain operational tools and there will be a subsequent reduction of availability of current tools used by the LWO and staff. Unless the USAF can develop new tools and data acquisition to replace the tools sustained by the AMU today, the LWO will see a reduction in forecast capability.

Modern Launch Weather Support

Following is a history of the implementation of the meteorological board recommendations, rephrased and condensed. These are categorized along the lines of the recommendations identified by the NRC report: (*indicates capability has lapsed)

1. Quantification of weather hazards
   a. Enhanced techniques utilizing lightning detection systems, field mill networks, radar, satellite data, evolved into the lightning assessment process used to issue Lightning Warnings (Phase I and Phase II). The approach reduces lightning weather downtime for ground ops by 50% saving several million dollars in lost productivity. KDP-KSC-P-3005 documents the KSC and CCAFS unique adverse weather policy.
   b. Jimsphere pair database has been improved dramatically using the Tropospheric Doppler Radar Wind Profiler (TDRWP), databases have been developed at all ranges
   c. Establishment of Data Archives. These are used in local forecast models
   d. Triggered lightning studies were performed over years, and the LLCC has been changed to reflect quantification of hazards for different cloud types and weather conditions
2. Observation system development and utilization
   a. USAF 915 MHz wind profilers are operational
   b. Radar: USAF WSR-74C was acquired by the Eastern Range in 1984 – Replaced by WSR-43/250 in 2009
   c. TDRWP is operational. (AC-205 in 2003 would have been lost without TDRWP) After STS-58, TDRWP was used to create a "range reference atmosphere" to accurately depict probabilities of wind shears, increasing launch availability
   d. Airborne instrumentation is required per LLCC with "severe clear" weather exceptions
   e. Ground Base Field Mill System is operational at ETR - Not at Western Test Range (WTR)
   f. Lightning Detection and Ranging System is operational (replaced by MERLIN 2016)
   g. Jimsphere pair databases provide knockdown winds with much greater precision, especially with the use of TDRWP.

h. AMU established to allow for deployment of new instrumentation and techniques which cannot be deployed directly into operational systems and processes
i. Satellite data feeds incorporated into local forecasts
j. *Weather Buoys established in coordination with National Data Buoy Center (NDBC) and the National Weather Service (NWS)

3. Analysis, forecasting, and decision making
    a. Meteorological Interactive Data Display System (MIDDS) is maintained and upgraded at ETR, companion system at WTR. Displays incorporate all data sets from all sources
    b. MIDDS is monitored by computer as well as the LWO and staff
    c. Use of synoptic and mesoscale models are used to provide guidance to forecast team, via the AMU derived locally tuned Weather Research and Forecasting (WRF) model
    d. Across agency, launch rules and rationale are precise and accurate
    e. Launch team training is extensive for USAF 45 SW Weather Squadron
    f. Decision trees and computer aided decision making informs LWO and staff
    g. LLCC are a set of complex rules used to avoid natural and rocket triggered lightning. NASA-STD-4010 (NASA Standard for Lightning Launch Commit Criteria for Space Flight) is in NASA agency signature, all agencies and ranges will use, required to be rigorously met [7, 8, 9, 10]
    h. Range LCC include boundary layer profiles of wind, temperature and moisture that are primarily used for predicting transport and dispersion of atmospheric constituents
    i. User LCC are limits for various weather categories such as near surface winds so the rocket can safely clear the launch tower, temperature for mechanical integrity of the rocket, and precipitation to avoid damaging the rocket while in-flight. Requirements also exist for upper level winds to avoid over stressing the space launch vehicle as it counter-steers through the actual winds versus the planned winds to stay on the correct trajectory and achieve the desired orbit. User LCC varies between launch vehicle programs and different configurations of vehicles in the same program. [11]
    j. NASA and other participants in space launches have shared roles in developing numerical models in dealing with weather elements crucial to the space program, through AMU and the Lightning Advisory Panel (LAP)
    k. NASA and other participants have developed the Lightning Protection and Analysis group to investigate observed lightning strikes near sensitive equipment, rockets and payloads to

assess damages on a rapid response basis in order to avoid launch and processing delays and to ascertain if there is a need to perform further investigation for lightning damage

l. Comparisons between ETR and WTR has been conducted and criteria match
m. *Comparisons between NSTS (now Space Launch System) with ELV (now Launch Services Program) are known. One major difference is that SLS requires TDRWP, LSP does not.

4. Organization and coordination of operations and research
   a. *Weather Support Office (WSO) established in 1987
   b. Team of expert civilian forecasters established within USAF CCAFS Weather Squadron
   c. Senior USAF civilian expert position established, senior USAF LWO
   d. *WSO director assigned with clear authority within Shuttle Program
   e. *Budget authority provided to WSO to ensure integrated and coordinated weather support across all manned and unmanned space programs
   f. *WSO obtained a budget and exercised line item authority to support and direct applied research efforts needed to solve operational problems
   g. *All meteorological support teams recognized WSO as having responsibility to direct, coordinate and supervise weather operation activities and research activities in support of all manned and unmanned space programs
   h. *WSO director periodically assessed whether or not (1) weather observations and observers meet the needs of the space program, (2) conducted thorough inspections to determine if observing systems are properly configured, calibrated and maintained, (3) ascertained whether or not available resources are being fully used to support space flight and (4) took actions to correct any problems identified
   i. *WSO staffed with atmospheric scientist capable of evaluating applied research activities, stimulating new applied research efforts to meet unaddressed needs of the space program. Skillsets required are meteorology, data modelling, software development, statistics
   j. WSO developed a weather support advisory committee to periodically assess for the WSO the organizational and technical issues that affect support for NASA space operations
5. Applied research, advancement in forecast (AARF) tools, techniques and technology
   a. AMU was established in accordance with NRC report section 5
   b. Lightning Advisory Panel was established in 1992 after Marshall Space Flight Center (MSFC), KSC and USAF agreed the LLCC needed a panel of experts to provide authoritative control
   c. Standing advisory panels of experts support both the AMU and the LAP and the LPA.

d. Less restrictive LLCC have been established using AMU developed radar scan strategies, scientific studies, and instrumentation. For example, the revised 1998 revision to LLLCC was subjectively estimated to decrease in the LLCC driven scrub rate by about 25%
e. AMU is co-located with 45SW Weather Squadron staff in Morrell Operations Center
f. AMU is used as the technology test bed for new forecast and visualization tools used by the LWO and staff
g. AMU developed and sustains these operational AMU tools for 45SW Weather Squadron use:
    i. Severe weather tools
    ii. Peak wind tools
    iii. Upper level wind tools – requires access to KSC Weather Data Archive site/server
    iv. Lightning forecast tools
    v. Daily forecast tools
    vi. Launch constraint tools (e.g. anvil tool)
    vii. Tools relating to the effective application of specific systems (e.g. radar scan strategy)
    viii. High resolution locally tuned weather model – requires access to NASA data sets

Drivers

KSC has strategically moved to become a multi-user spaceport with increasing launch rates. Being located in the subtropics and in the most active lightning region in the United States, the absence of robust evaluation of LCC and weather infrastructure will endanger launch missions. Ground operations and launch will cumulatively undergo greater delays and scrubs.

There are three types of requirements the LWO evaluates: Lightning Launch Commit Criteria, Range Launch Commit Criteria, and User Launch Commit Criteria. However, the only mandatory weather instrumentation required for evaluation of these launch commit criteria and launch is the weather balloon, because balloon data is always required for the loads and steering programs in the guidance system of the rocket. Other weather infrastructure is required to be operational only if all weather LCC requirements are not clearly met based on observations. The LCC evaluation system is intentionally designed this way, so a launch is not required to be scrubbed due to unavailability of the full suite of weather infrastructure if the weather is "severe clear".

1. LLCC are a set of complex rules used to avoid natural and rocket triggered lightning. NASA-STD-4010 is in final NASA agency signature. All agencies and ranges will use NASA-STD-4010, which is required to be rigorously met [7, 8, 9, 10]
2. Range LCC include boundary layer profiles of wind, temperature and moisture that are primarily used for predicting transport and dispersion of atmospheric constituents.
3. User LCC are limits for various weather categories such as near surface winds so the rocket can safely clear the launch tower, temperature for mechanical integrity of the rocket, and precipitation to avoid damaging the rocket while in-flight. Requirements also exist for upper level winds to avoid over stressing the space launch vehicle as it counter-steers through the actual winds versus the planned winds to stay on the correct trajectory and achieve the desired orbit. User LCC varies between launch vehicle programs and different configurations of vehicles in the same program. [11]

In order to maintain a functional range, and not to simply wait for clear calm days to launch, forecasters need ways to find more available days, which requires experience, expertise, advanced observation systems, and a variety of analytical and forecast tools. The LWO needs to be in close communication with the launch team and to establish a relationship of trust. 45SW Weather Squadron capabilities are partially funded by NASA per the Webb-McNamara Agreement [13] at levels considered fair to USAF and NASA in proportion to range use. It is imperative that NASA continue to provide weather support leadership and maintain communication with the USAF in order to ensure the USAF civilian staffing approach established by cross agency board recommendations persists far into the future.

A new and growing gap between the NASA recommended approach and the current state has been created with the loss of clear authority, the loss of line funding authority, and a loss of a high level advocate to defend existing weather support capabilities.

The last KSC Weather Officer retired in January 2017, and that position was not backfilled. There is a current opportunity to revise the staffing approach to establish a new NASA Agency WSO Director instead of backfilling the KSC Weather Officer position. The new WSO should review the status of staffing at other center weather support offices to ensure the post-Shuttle weather support across the agency is appropriate.

Obstacles

The dedicated funding for weather support from Human Operations and Exploration Mission Directorate (HEO) ended with the end of the Space Shuttle Program, leaving the KWO with a reduced budget drawn from within individual KSC located programs.

All KSC located launch programs, except for the tri-program, essentially buy launch services for payloads. Due to the USAF 45SW implementation of agreements covered by Commercial Space Launch Act (CSLA) legislation, the USAF does not charge for indirect weather support services from CSLA customers. Launch service providers fund only a small fraction of launch weather support via their agreements with USAF and NASA. Payload customers do not reimburse weather infrastructure costs when they procure launch service contracts.

The KSC Chief Financial Officer (CFO) made extraordinary efforts from 2015-2017 to assess NASA KSC resident program customers and the KSC Center Management and Operations office to pay for a level of weather support that meets basic launch and ground operations requirements. The KSC CFO is also developing reimbursement strategies for commercial launch providers in order to obtain an increased share of funding from commercial launch providers. It has proven difficult to develop a requirements-based reimbursement scheme, because some launches under clear weather conditions will not require the total suite of instrumentation and analysis.

The KSC resident launching programs, while they are among the chief ultimate beneficiaries of the increased flight safety provided by the advanced meteorological support of launch, are not individually chartered to support weather infrastructure, nor is the multi-program assessment an effective means to support a lean weather office.

As the weather professionals who were involved in the Challenger and AC-67 mishaps retire, there is a loss of corporate knowledge regarding previous accident investigations and lessons learned. Funding requirements need to be identified for smooth transition of personnel into leadership roles and to support long term sustainment for weather infrastructure.

If NASA does not re-establish a firmly funded WSO with a focused mission and line budget, then steps need to be taken to coordinate within NASA and other agencies to revisit past agreements and to ensure weather support does not degrade. The other option would be for NASA to work with USAF to quantify and accept the risk of maintaining the status quo and accepting lower levels of weather support of American space flight.

Ancillary Problems

KSC and CCAFS have state-of-the-art instrumentation systems (i.e., radar, lightning detection systems, a ground based field mill network, an array of weather towers), and sophisticated forecasting methods and displays to predict and warn against weather hazards in support of ground operations not directly associated with launch. If these meteorological systems and tools are not maintained, Phase II warning periods are likely to double. This increase is attributable to systems degradation leading to decreased detection, accuracy, and/or detection efficiency. Phase II lightning warnings account for approximately 150 hours per year and Phase I lightning warnings account for approximately 450 hours per year at any point on KSC.[12] On average, operations suspended during Phase II are experiencing about a 30 minute opportunity loss each day, which increases to 60 minutes if KSC and CCAFS meteorological systems are allowed to degrade.

The funding for the Lightning Protection and Analysis group is small, on-demand and threatened. If that funding is cut, NASA will see a loss of capability to rapidly respond to observed lightning strikes. As an example of downtime that occurred when the 24/7 lightning strike alerts were not available, the STS-115 launch countdown operations start was delayed by several days due to lack of information that lightning had occurred late on a Friday and retest was required prior to start. Had the lightning strike been identified automatically, the launch team would have had the option to retest over the weekend.

The USAF 45SW Weather Squadron uses specialized local forecast models which require data feeds from synoptic and mesoscale forecast models from outside of USAF and NASA. The firewall requirements for USAF information technology networks prohibit USAF 45 SW Weather Squadron from making direct access to the forecast websites required, so NASA has established mirror sites within the NASA firewall to allow for the forecast models to be imported for use by the USAF. Without these synoptic and mesoscale models, the local models will not function properly.

The USAF 45SW Weather Squadron uses specialized local forecast models that depend on KSC weather data archives to ensure local forecast model functionality. Without the KSC weather data archives, the local models will not function properly.

The USAF 45SW Weather Squadron uses specialized local forecast models and strategies that are products developed by the AMU and sustained by the AMU. Without the AMU, the USAF will need to obtain a way to provide software sustainment for these operational products, or else to replace these products. The USAF 45SW Weather Squadron does not have USAF authority to develop new software tools on operational consoles used for weather support. Without the AMU, the USAF will need to obtain a way to provide a technology transfer capability to allow for new technology or replacement technology to be transferred into an operational status.

On a separate note, Launch Services Program (LSP) and the Space Launch System (SLS) Program have divergent Range LCC. The SLS requires an operational TDRWP, and LSP does not consider the TDRWP as a requirement. While this divergence is not necessarily a violation of previous board recommendations, the AC-67 mishap board did recommend that the divergence between manned and unmanned programs should converge where practical and be examined and the associated risks quantified going forward.

Call to Action

To meet the unusual demands of rocket-operations weather forecasting, to ensure effective and safe weather services for processing, launch and landing, and to bring about substantial improvements in weather support, it is imperative that NASA give clear and unambiguous authority to a Weather Support Office. The WSO will require sufficient budgetary authority to ensure an integrated and coordinated meteorological support program for all phases of the manned and unmanned space programs. Weather support for manned and unmanned space flight should be provided as a single cohesive program coordinated through the WSO.[14] The funding for this office should come directly from HEO so that NASA KSC internal budget priorities do not threaten weather support for the agency and the agreements made with the USAF for joint weather support. The WSO must be tasked to look forward and to ensure funding is sufficient to provide quality weather products and services for years to come. The WSO must work across multiple NASA Centers (MSFC, JSC, and Wallops Flight Facility (WFF)) and other government agencies (USAF, Federal Aviation Administration (FAA), National Oceanic and Atmospheric Administration (NOAA)) to ensure weather support is adequate to protect the public, the workforce and high value assets.

If the KSC Weather Officer position is eliminated and the WSO is not re-established, NASA will have rescinded corrective actions put in place after serious weather-related launch failures. Further reductions in weather support staff and funding will have a direct impact on NASA's ability to ensure the other weather support improvements remain in effect. Loss of weather support will result in increased exposure to personnel and assets and loss of operational and launch availability. Although the cost of maintaining weather support and infrastructure is substantial, it represents only a very small fraction of the potential losses that poorly forecast weather conditions can cause during rocket launch and recovery operations. [3]

The state of the NASA and USAF response to the corrective actions and recommendations from the meteorological boards is attached in a color coded spreadsheet indicating which items are properly implemented and which items are threatened or in a state of lapse.

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