Tailoring the Advanced Weather Interactive Processing System (AWIPS) for Space Launch Range Support

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1. INTRODUCTION

Access to space is generally taken for granted as part of our modern society. In the United States, the two primary launch locations are The Western Range (WR) at Vandenberg Air Force Base, California and the Eastern Range (ER) at Cape Canaveral Air Force Station and Kennedy Space Center (KSC). The Air Force Space Command has the responsibility to operate the ER and WR, providing common services and ensuring public safety. In addition to space launches, the ER and WR also serve as test ranges for ballistic missile and other tests. Figure 1 shows the extent of the ranges.

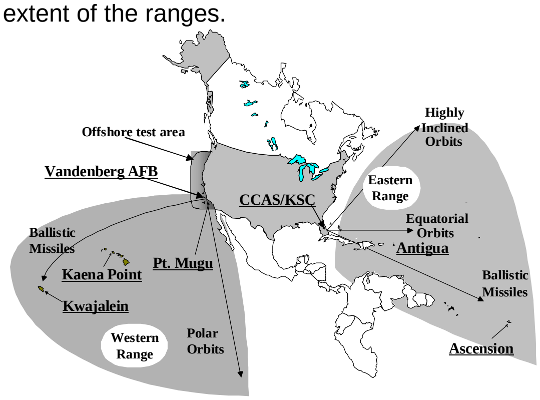

Figure 1. The Eastern Range and Western Range cover large areas necessary to accommodate equatorial, high inclination and polar orbits as well as ballistic missile and other tests such as aircraft flights in the offshore corridor off the west coast.

The Air Force provides comprehensive operational meteorological services to the Eastern and Western Ranges. These services include weather support for personnel and resource protection, pre−launch ground processing, and day−of−launch operations for launches by the Department of Defense, National Aeronautics and Space Administration (NASA), and commercial launch customers.

In the mid 1990s, Space Command undertook an effort to modernize the two ranges. The Range Standardization and Automation (RSA) program is designed to improve efficiency and reduce costs by providing more automated, standard systems to the space launch ranges. As part of this modernization effort, the Mission Systems division of Lockheed Martin is completing development and delivery of the infrastructure, instrumentation, communication and software applications necessary to operate the ranges. It is beyond the scope of this paper to describe the details of the overall architecture being implemented by RSA. Here, we focus on the integration of range forecasting functionality into the National Weather Services' (NWS) Advanced Weather Interactive Processing System (AWIPS) which address the weather launch requirements and instrumentation used to collect the required data, and method of dissemination of that information to the launch directors.

2. WEATHER SUBSYSTEM OVERVIEW

The RSA weather subsystem is designed to assimilate data from various types of local instrumentation including instrumented towers, radar wind profilers, sodars, various lightning detection systems, and the balloon based sounding systems. As shown in Figure 2, the infrastructure is implemented on two separate local area networks (LANs) . The Operations Control Center (OCC) LAN interfaces to all local instrumentation and is used to acquire, quality control, and archive local data, as well as to distribute data and decision products. The AWIPS LAN is implemented in much the same way as most NWS installations and uses the new Linux based architecture. Local data acquired by servers on the OCC LAN are then

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formatted and sent to the AWIPS LAN where they are combined with NOAAPORT and NEXRAD data acquired directly by the AWIPS.

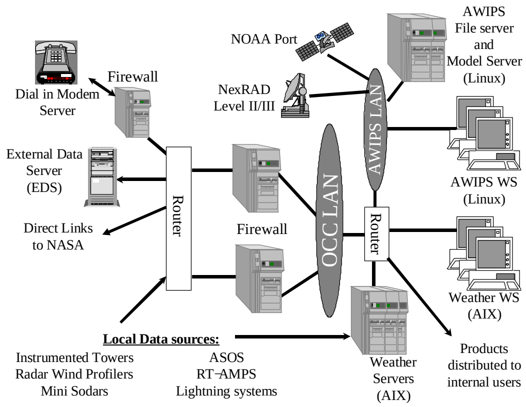

Figure 2. The weather support subsystem consists of local instrumentation, communication and the automatic data processing equipment required to acquire and process data. The AWIPS LAN is implemented in the same manner as other National systems to maintain compatibility.

The AWIPS LAN also supports a mesoscale model server used to run a local area analysis and forecast model.

3. FORECASTING REQUIREMENTS AT THE RANGES

3.1 Eastern Range

Weather has a significant impact on launch and daily operations at the Eastern Range NASA's KSC. Weather contributed to 34% of total launch scrubs and 51% of launch delays from 1 October 1988 to 25 Aug 2000 (Boyd et al.2002). The cost of a launch scrub varies from $150,000 to over $1,000,000 depending upon the launch vehicle. Other impacts include possible delays in future launch schedules, and the human element of repeated stressful launch attempts.

The USAF's 45th Weather Squadron (45 WS) evaluates and forecasts weather operationally for the ER and KSC. This support includes resource protection, pre−launch ground processing, and day−of−launch operations for up to 40 launches per year by the Department of Defense, NASA, and commercial launch customers. The launch vehicles currently supported include the Titan, Atlas, Delta, Athena, and Pegasus rockets; the Space Shuttle; and the Trident ballistic missiles.

In addition to launch operations, the 45 WS provides weather support to daily operations at Cape Canaveral Air Force Station (CCAFS), KSC, Patrick AFB, and the E−8C Joint Surveillance Target Attack Radar System (JSTARS) unit in Melbourne, Florida. Weather warnings and advisories are issued for these areas (also shown in Figure 3) by the forecaster at Range Weather Operations at CCAFS. Furthermore, Patrick AFB has an active airfield where contracted observers monitor the weather, and forecasters from CCAFS provide flight forecasts for aircrews.

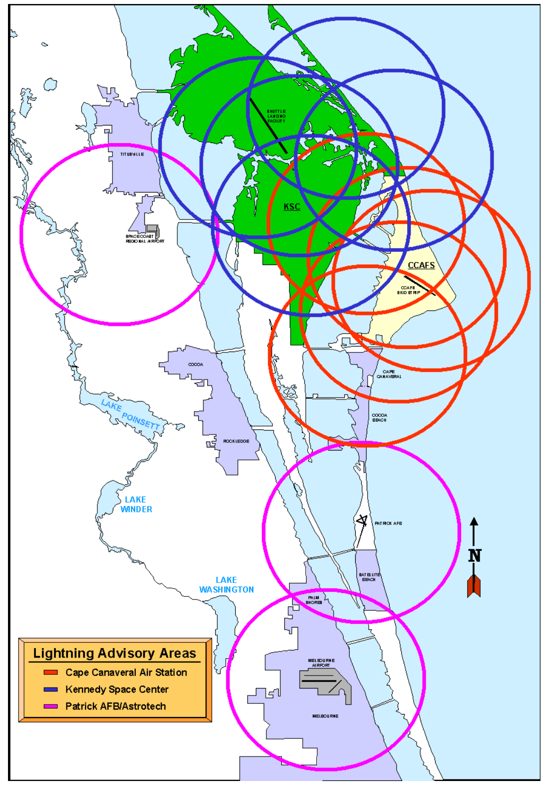

Figure 3. Warning and advisory areas covered by the 45 WS range weather operations.

To provide the high−quality weather support required for launch and daily operations, the 45 WS uses weather systems unique from other USAF weather units. A large network of weather towers, wind profilers, lightning sensors and field mills (instruments which measure the electric field at the surface and detect electric discharges) are part of the range weather network. Ideally, these data should be integrated into one system at Range Weather Operations to allow weather personnel to evaluate the large amounts of data available. Currently, the 45 WS uses a derivative of the Man computer Interactive Data Access System (McIDAS) to accomplish this task. With the delivery of Lockheed−Martin's Range Standardization and Automation Weather Product in 2003, Forecast Systems Lab's AWIPS will integrate the complete complement of data available on the range as well as data available on the NOAAPort Receive System.

3.2 Western Range

Vandenberg Air Force Base has a unique geographic location that provides America with the capability to launch satellites into polar orbit while the threat of over−flying population centers is minimized. This mission, crucial to national security as well as commercial interests such as communications, land resource surveillance, and space research, is dependent upon the successful launch of a wide variety of spacelift boosters including Delta, Titan, Atlas, Pegasus, Taurus and Minotaur. Meteorological forecasting responsibility for these missions falls under the purview of the USAF 30th Weather Squadron (30 WS), based at Vandenberg.

The Air Force relies on the 30 WS to provide meteorological monitoring on "the window to the Pacific" as well as operational testing of the Minuteman and Peacekeeper ICBM programs including the National Missile Defense program. The 30 WS analyzes and forecasts operational weather for the Western Range and Vandenberg Air Force Base. Forecasters provide resource protection, pre−launch, day−of−launch, and post−launch operations for up to twenty scientific, DoD and commercial launches per year, in addition to providing air operations support for a variety of military aircraft. Weather is a critical part of every operation, affecting pre−launch and ground operations as well as day−of−launch and post−launch functions. Since 1988, approximately 34.8% of all launch missions at the Western Range were scrubbed due to weather.

3.2.1 Weather's Role in Western Range Operations

Vandenberg's space flight activities involve extremely expensive and environmentally sensitive systems. Complex, weather sensitive requirements for ground processing, launch and recovery operations are common. Downrange and remote sensing sites also have environmentally sensitive systems incurring stringent weather−related constraints. A variety of weather parameters affect launch operations. Lightning, strong winds, temperatures, precipitation and even sea state conditions have profound effects on launch operations.

Vandenberg Air Force Base, located in Santa Barbara County, California, is the third largest Air Force base in the nation, encompassing more than 98,400 acres. The proximity of the base to the Pacific Ocean plays a major role in Vandenberg's weather. Topography also has a significant effect because of abrupt changes in elevation over short distances. The Pacific Ocean and mountainous elevations to over 2,000 ft make meteorological support to mission operations a challenge.

Wind plays a key role in Western Range operations and launch drift winds are of concern both to launch agencies and range safety. The winds over this large complex can vary greatly in direction and speed depending on location. The mountainous terrain surrounding the base significantly affects wind direction and speed, especially in the winter and spring. Westerly winds tend to funnel through coastal valleys and canyons and increase in speed due to the channeling effect. These localized wind perturbations can effect toxic hazard forecasts and launch operations.

3.2.2 Use of AWIPS at the 30th Weather Squadron

To help mitigate these effects, the weather support structure at the Western Range is in the midst of a significant upgrade. Upon completion, this upgrade will provide tower−mounted sonic anemometers, temperature/humidity sets, radiometers, and soil moisture sensors, 915 MHz Boundary Layer Wind Profilers, Mini−SODARs, a new GPS balloon tracking system and a 50 MHz Doppler Radar Wind Profiler. The upgrade also includes version 5.1.2 of AWIPS software.

The 30 WS is the only Air Force weather squadron that currently uses AWIPS for spacelift range support. AWIPS integrates GOES satellite imagery, forecast models and field observations. The 30 WS's upgrade version of AWIPS is enhanced by ingest of *in situ* data and a high−resolution mesoscale model for forecasting.

FSL developed a special version of MM5 for Vandenberg. This model is routinely run in 4 km and 16 km resolutions. Model outputs will be customized to provide products that enhance forecast support at the Western Range. Upon final upgrade delivery, the mesoscale model will run on AWIPS locally, with a 24−hr run performed every 6 hrs. The model run currently takes approximately 5.5 hrs to complete. However the upgraded version decreases processing time to a few hours and increases model resolution to 1 km.

AWIPS is also used to display the Aviation Model (AVN) and Nested Grid Model (NGM) weather forecast models twice per day. The Medium Range Forecast Model (MRF) is available based only on 00Z data. Western Range forecasters do not reanalyze the models; however, they do have the capability to display model features using AWIPS graphics. AWIPS enhances the forecasters ability to initialize and analyze forecast models through graphics overlay capability.

Current AWIPS graphics capabilities are of great value to the Western Range forecaster. RSA additions will further enhance those capabilities and incorporate the local mesoscale model. These capabilities provide a new integrated approach to the forecast challenge at the Western Range.

4. AWIPS Enhancements

4.1 System Description

The National Weather Service has spent many years creating a forecasting tool for weather forecast offices during its modernization efforts. The RSA project is effectively leveraging this work for use at the ranges. Working with FSL, the RSA project is incorporating site specific data and visualizations into general purpose functions that can be used by all weather forecasting offices within the NWS in future versions of AWIPS.

The RSA AWIPS is using Linux PC and NFS servers. Mimicking the NWS' proposed hardware upgrades, the RSA is implementing high−end IBM IntelliStation PCs for data display with an IBM eServer series 350 network file server for data ingest, decoding, and storage.

4.2 Data

The RSA weather product will use the data from NOAAPORT available over satellite broadcast. Data are available on four channels −−the NWSTG data, GOES−East, GOES−West, and the OCONUS data set (including a 4 satellite composite over the northern hemisphere). Information on the abort landing sites will be available on the RSA system.

The RSA highly depends on vertical data sets. RTAMPS balloons, Mini−Sodars, 915 MHz profilers, 50 MHz profilers are available at each range. The standard AWIPS system can ingest and display local data at every office, but the data sets are limited to surface "mesonet" type data. FSL enhanced the local data ingest for RSA by creating an avenue to ingest and display profiler and rawinsonde data.

In addition, the ranges have a dense network of user towers with surface and 54ft instrumentation. Additional work was needed to enhance the surface ingest to incorporate the second level of data for storage.

Future work will focus on the lightning data available at the ranges. In particular, the eastern range at Cape Canaveral has four types of lightning detection available. These are

- National lightning product available on NOAAPORT
- Field Mills
- LDAR
- Local Lightning

These data present a great challenge to add to the AWIPS local ingest schema. Of note, the LDAR can have upwards of 30,000 points per minute. Adding a lightning component to the AWIPS local data ingest and making these data available in a timely manner will be especially challenging.

Finally, to enhance the exceptional local modeling that will be available on the RSA system, Level II WSR−88D data will be added to the ingest system.

4.3 Visualization

RSA requirements added additional scales for display. These included the TAL sites over northern Africa, the Marshall Islands, and the South Pacific.

Also incorporated into AWIPS are new overlays such as range rings. These include rings with a user defined radius centered on a launch pad as well as pre−defined rings centered over areas the 45 WS monitors for weather warnings and advisories. Range rings are required to assist Launch Weather Officer's (LWO) in evaluating Launch Commit Criteria (LCC) and assist forecasters when determining weather warnings and advisories for affected areas (Figure 3).

Because of the enhanced upper air data sets, additions were made to the display system to handle these dense data. First, a "variable Vs height" display was added to the volume browser, allowing inspection of data on the vertical scale and overlay of these data sets. Additional sources were added to the volume browser menu to account for the rawinsonde and profiler data available from the local range data sets. Care was taken to include re−rendering when zooming on the vertical scales.

Two new profiler perspectives have been introduced. These allow the user to inspect all mini−sodars or profilers at the same time on a mapped scale.

The RSA requires a wind convergence contour. The decision was made to include an on demand contour of any point data set on any scale. Future upgrades will move this functionality into the volume browser which will allow any data type to be contoured.

Launch briefings and inter−range communications use a closed circuit TV to relay information within the base. To incorporate this function, an editing tool has been added to allow annotations and weather symbols to build briefing charts for transmission to the users. The weather system must have the capability to allow the LWO to create and display a briefing which includes weather information from NOAAPORT, local information such as upper air data from locally launched balloons, and data from the network of instruments across the range. Also included in the briefing are slides created by the LWO which display launch−critical information such as the launch forecast and status of the LCC. The LCC are a set of complex rules designed to ensure the vehicle does not launch during hazardous weather conditions.

Future additions to the display will add a 3−D lightning product for the voluminous LDAR data set. This will be the first integration of the three dimensional rendering into AWIPS.

Future additions also include an alert monitor which will visually or audibly notify the LWO when thresholds of data have been exceeded.

5. Local Analysis and Prediction System

In addition to the standard AWIPS data server and display workstations, each of the range installations incorporate a data assimilation system running on a

Linux cluster application server. The cluster consists of 8 dual−processor compute nodes employing 1 GHz Intel processors. An additional dual−processor node serves as a front−end processor. This server hosts the Local Analysis and Prediction System (LAPS, Albers et al. 1996), coupled with the NCAR/PSU Fifth−Generation Mesoscale Model (MM5, Grell et al. 1995), as a local data assimilation and forecast system. This system, described in detail in Shaw et al. (2002), provides local analysis and forecast grids at high spatial (1.1 km grid spacing) and temporal (hourly) resolution. These gridded fields are used to support local forecasting efforts for the 0−24 h forecast period as well as provide input for atmospheric dispersion models. This system marks the first known fully−integrated implementation of a local forecast model within AWIPS for fully operational applications.

6. Using AWIPS for Evaluation of LCC

During the launch countdown, the Launch Weather Team (LWT) monitors range weather data and evaluates the LCC. The LCC are each determined to be either red if the criterion is violated or green if not. Frequent briefings on the LCC are provided to the Launch Director who uses the information to make a Go/No Go decision for the launch.

With the integration of the range data, the NOAAPORT weather data, ER overlays, and an alert monitor, AWIPS is a valuable tool for evaluating LCC. Many LCC include a weather data type, time (duration) since occurrence, and distance threshold from the flight path or launch pad in nautical miles (NM). The alert monitor in AWIPS can be set to alarm for these variables providing evidence to the LWO when an LCC may need to be changed from green to red or vice versa. The following are examples of using AWIPS overlays and the AWIPS alert monitor to assist the LWO in evaluating LCC. For a complete listing of the LCC, refer to Roeder et al.(1999).

6.1 Example of Using LCC Range Rings for Evaluation

Attached Anvil LCC: "Do not launch if the flight path will carry the vehicle through nontransparent parts of attached anvil clouds. Do not launch if the flight path will carry the vehicle within 5 NM of nontransparent parts of attached anvil clouds for the first three hours after the time of the last lightning discharge that occurs in the parent cloud or anvil cloud. Do not launch if the flight path will carry the vehicle within 10 NM of nontransparent parts of attached anvil clouds for the first 30 minutes after the time of the last lightning discharge that occurs in the parent cloud or anvil cloud." (Roeder et al. 1999).

The scenario in Figures 4 and 5 clearly indicate the need for range ring overlays when evaluating the Attached Anvil LCC. In this case, anvil clouds from distant thunderstorms are encroaching upon CCAFS. In Figure 4, the anvil clouds are clearly threatening the area, and the range rings provide a valuable tool in determining if the anvil cloud is within 10 NM of the launch pad. Figure 5 provides clear evidence that lightning is indeed occurring from the storm producing the anvil cloud, which indicates, according to the LCC, that if the anvil cloud moves into the 10 NM range ring, the LWO will change the Anvil Cloud LCC status to red.

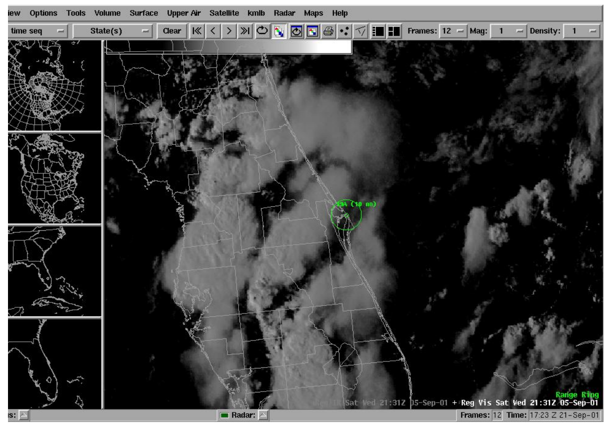

Figure 4. AWIPS display of visible GOES−East satellite imagery with cumulus and anvil cloud. Also included is the 10 NM range ring centered on Shuttle pad 39A.

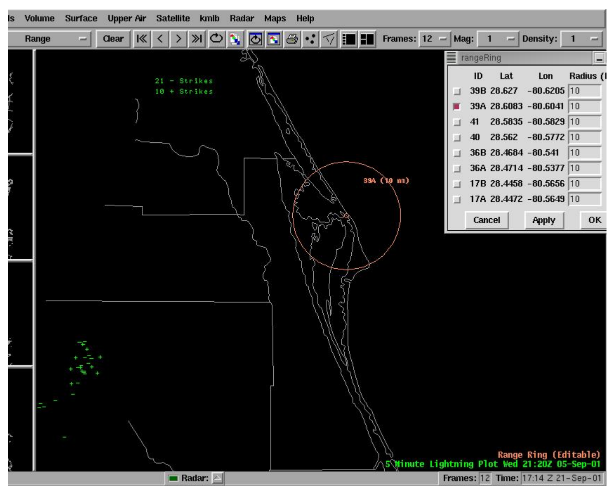

Figure 5. AWIPS display of NLDN NOAAPORT lightning data for same time period as Figure 4.

6.2 Example of Using Alert Monitor for LCC Evaluation

Surface Electric Fields LCC Example: "Do not launch for 15 minutes after the absolute value of any electric field measurement at the surface within 5 NM of the flight path has been greater than 1,500 Volts/meter (V/m)" (Roeder et al. 1999).

This LCC can easily be defined as an alert criterion in the AWIPS alert monitor. Since the AWIPS ingests range local data including the field mill data, an alert can be defined to monitor the data (atmospheric electrification in V/m), the location of the data (within 5

NM from the launch pad), and the duration of time since the threshold was reached (15 minutes). AWIPS will provide an audible and visual alert to the user when the threshold value is exceeded. When the V/m measured falls below the threshold value and remains so for 15 minutes, AWIPS will alert the LWO again indicating a possible change in the status of the LCC. NOTE: The LWO determines the change in the LCC; AWIPS does not. An alert from AWIPS for an LCC is simply a tool provided to assist the LWO in evaluation of the LCC. Table 1 provides the data AWIPS can monitor to determine if LCC variables exceed a defined threshold value.

TABLE 1. Example of data AWIPS can monitor to determine if LCC variables exceed a threshold value.

Variable	**Satellite**	**Radar**	**UpperAirData**	**FieldMills**	**LtgSensors**
Lightning					X
Cloud Present	X	X			
Cloud Location		X	X		
Cloud Tops		X			
Cloud Thickness		X	X		
Field Mill v/m				X	
Precipitation		X			
Cloud Type		X	X		
Radar Reflectivity		X			
Radar Bright Band Present		X			
Convective Clouds		X			
Liquid in Cloud		X			

7. REFERENCES

Albers, S., J. McGinley, D. Birkenheuer, and J. Smart,1996: The Local Analysis and Prediction System (LAPS): Analysis of clouds, precipitation, and temperature. *Wea. and Forecas*t., **1**1, 273−287.

Boyd, B., D. Harms, D. Beberwyk, M. Christie, and J. Weems, 2002: Facilitating the Use of Environmental Information for Space Launch Decisions, *Third Symposium on Environmental Applications*, Orlando, FL, Amer. Meteor. Soc.

Grell, G. A., J. Dudhia, and D. R. Stauffer, 1995: A description of the fifth−generation Penn State NCAR Mesoscale Model (MM5). NCAR Technical Note TN−398+STR, 122 pp.

Roeder, W., J. Sardonia, S. Jacobs, M. Hinson, A. Guiffrida, J. Madura, 1999: Lightning Launch Commit Criteria at the Eastern Range/Kennedy Space Center, 1999; 37th AIAA Aerospace Sciences Meeting And Exhibit, 10−15 Jan 99, Reno, NV, Paper 99−0890, 9 pp.

Shaw, B. L., S. C. Albers, J. A. McGinley, L. S. Wharton, T. L. Wilfong, C.L. Crosiar, and D. E. Harmes, 2002: A completely integrated, cost−effective, local data assimilation and forecasting system to support space launch range operations. *Interactive Symposium on AWIPS*, Orlando, FL,
Amer. Meteor. Soc., (this volume).