1.5 Advanced Weather Projects To Improve Space Launch From The Eastern Range And Kennedy Space Center

William P. Roeder Francis J. Merceret[1] Billie F. Boyd Frank C. Brody[2] and Dewey E. Harms
45th Weather Squadron, USAF [1]NASA, Kennedy Space Center [2]Spaceflight Meteorology Group, NWS

1. INTRODUCTION

Weather support to space launches from Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC) in east central Florida is highly specialized and atypical from most other types of operational meteorology. The weather requirements for space launch, pre-launch processing, post-launch activities, and Space Shuttle flight operations are extremely complex.

The USAF 45th Weather Squadron (45 WS) provides all operational weather support to unmanned launches from CCAFS including Titan, Atlas, Delta, Athena, Pegasus launch vehicles, and Trident ballistic missile tests (Harms, et al, 1999). The 45 WS also provides pre-launch, launch, and post-launch support to the manned Space Shuttle. The 45 WS duties are briefly listed in Table-1.

The NWS Spaceflight Meteorology Group (SMG) (Brody, 1997) provides landing weather support for the Space Shuttle. This includes forecasts and briefings to NASA for launch abort landing sites in the U.S., Europe, and Africa; for on-orbit U.S. primary landing site options; and for planned end-of-mission landings. U.S. landing sites are KSC, Edwards AFB, CA, and White Sands Space Harbor, NM. SMG supports the International Space Station with forecasts for worldwide emergency landing sites for the Soyuz crew return vehicle, and provides local hazardous weather advisories for the Johnson Space Center in Houston, TX.

The world's most diverse and dense suite of operational weather sensors (Fig. 1) is used to support these requirements (Harms, et al., 1998). This is especially true of the atmospheric electricity instrumentation (Harms, et al., 1997). However, these same weather sensors also complicate the weather support in that it is difficult to maximize their use by forecasters, due to the non-standard data types and the sheer volume of data.

Finally, the weather itself can be very challenging to analyze and forecast in central Florida. During summer, the synoptic drivers are so weak that subtle mesoscale processes dominate. Weak boundary interactions, which would normally be secondary or tertiary effects elsewhere, control the formation of convection. Examples of boundaries include the sea breeze from the Atlantic Ocean, the sea breeze from the Gulf of Mexico, the Indian River Breeze, the Banana River Breeze, convective outflows, horizontal convective rolls, shear lines from washed out fronts and troughs, the Trailing Convergent Line, soil moisture breezes from unequal heating across rain/no-rain boundaries, and other horizontal convergent lines. Even cloud shadow boundaries are sometimes used to predict where thunderstorms will form. These many land-water surfaces lead to a complex frictional-stability environment that also makes forecasting winter winds difficult.

TABLE-1. 45 WS Florida Weather Duties

45 WS FLORIDA WEATHER DUTIES
LAUNCH
Lightning Launch Commit Criteria (LCC) (constant for all space launch vehicles)
User Launch Commit Criteria (varies by vehicle)
Tower Rollback Exposure Forecast
Weather Guidance To Other Launch Decision Offices: 'Loads' (upper level wind aerodynamic loading), Toxic Dispersion, Debris (parts falling onto uncontrolled areas), BLAST (over-pressure from rocket explosion breaking windows in nearby towns)
PRE-LAUNCH
Pre-Launch Forecasts (typically beginning 3-days before launch)
Vehicle Rollover / Rollout Forecasts Crane Operations: stack/destack rocket segments, mate/demate payload, etc.
Surface Move Of Major Components
Tanking Forecast
SPECIAL OPERATIONS
Space Shuttle Ferry Flight
Shuttle Solid Rocket Booster Recovery At-Sea
Shuttle Rescue Exercises
Ultra-Large Aircraft Deliveries
Large Distance Barge Deliveries
ROUTINE 24/7/365 DUTIES
Weather Watches / Warnings / Advisories
Airfield Forecasts
Military Aviation At Patrick AFB / Melbourne Airport
Daily 7-Day Planning Forecast
Staff Meteorology Support

2. ADVANCED WEATHER PROJECTS

The following 13 weather projects are identified as potential areas to significantly improve meteorological support to space launch from the CCAFS/KSC (Table-2). In this context, "advanced" projects are those

Corresponding Author: William P. Roeder,
45 WS/SYR, 1201 Edward H. White II St.,
MS 7302, Patrick AFB, FL 32925-3238
E-mail: william.roeder@patrick.af.mil
Website: https://www.patrick.af.mil/45og/45ws/index.htm

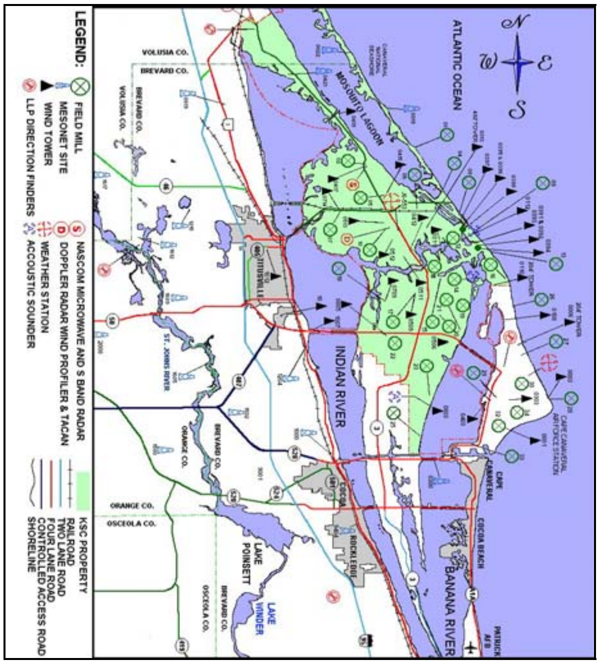

Figure 1. Weather sensors at CCAFS/KSC.

that are too large, too expensive, or too technical to be done by the operational weather support offices or by their normal operational research avenues (Roeder and Harms, 1998). A brief overview of the topics follows. More details are in a 45 WS background paper (Roeder, 2002).

TABLE-2. Advanced Weather Projects

NO.	PROJECT
1	Extremely Advanced Mesoscale Numerical Weather Prediction
2	Dual-Polarization Weather Radar
3	Automated Weather Warning Dissemination
4	Fill Data Voids
5	Integration and Display of Weather Sensors
6	Improved 50 MHz Doppler Radar Wind Profiling (DRWP)
7	AFIT Weather Laboratory Upgrade
8	Cloud Depiction Device
9	Global Positioning Satellite-Precipitable Water Micro-Network
10	Improved Lightning Launch Commit Criteria
11	Automated Weather Forecast Advisor and Training Assistant
12	LPLWS Upgraded Displays
13	Remote Sensing Electric Field Profiler

2.1 Extreme Numerical Prediction

Extreme numerical modeling likely offers the most cost-effective way to make far-reaching improvements in many areas of weather support to the space program at CCAFS/KSC. In this context, “extreme” means many aspects of the numerical model will have to be extremely advanced. For example, extremely high horizontal resolution will be needed. The authors envision multiple nested grids from the southeast US region down to the local area, with boundary conditions set by the most appropriate national model. The inner-grid, covering the CCAFS/KSC/nearby ocean and mainland, will likely need a grid-spacing of about 100 m to directly model the small scale convection in the local area. Two-way forcing will certainly be a requirement to ensure horizontal consistency across the grids. A commensurate high vertical resolution will also be needed. Extremely advanced initialization techniques will be needed. Radar and satellite imagery will play a large role in identifying pre-existing convergent lines. These convergent lines and their interactions are absolutely essential to predicting where convection will form in the summer in Florida. The data assimilation scheme will have to be able to handle very non-uniform distribution of data, very disparate types of data, and data with widely varying valid times and update frequencies.

The model physics will also need to be very advanced. For example, Kelvin-Helmholtz waves can play a role in initiating convection, especially behind the sea breeze front (Rao, 1997). Even infra-sonics have been suggested as a possible initiator of local convection. Gravity waves, and perhaps even acoustic waves, will need to be allowed in the model. These phenomena are intentionally filtered out of current models to reduce numerical instability. The physics will need to be especially adept at the accurate generation of convective downdrafts and outflow boundaries.

The local area has many data voids, especially over the ocean. Additional sensors (see para 2.4) will be needed, along with better use of the current sensors, to maximize the benefit of advanced numerical modeling. For example, satellite detection of soil moisture would be very useful. Doppler radar radial velocities can be useful in detecting subtle boundary lines. Dual Doppler radar would be useful in initializing the local wind fields.

Advanced modeling techniques like nudging, as opposed to mere blending, and ensemble forecasting will likely be needed. The latter will be especially useful in generating probability forecasts.

In addition to the technical aspects of the numerical modeling itself, operational use of the model’s output must be considered. Advanced visualization and interpretation tools will be needed to maximize operational benefit from the model.

The extreme numerical model should improve all elements of space launch weather forecasting, especially timing and location of thunderstorm onset and ending of thunderstorm, Lightning Launch Commit Criteria (LCC) forecasting, and Space Shuttle landing forecasts, especially cloud cover. There will be equivalent collateral benefit to the Range Safety models for toxic dispersion, blast, and debris.

Florida has many large diverse users with large operational impacts from weather. This creates the opportunity to cost-share a centrally-located widely-shared model. One avenue might be a university spin-off company to run and maintain the model, custom-tailoring the products to individual customers. Likely participating agencies include: USAF space program, KSC, NWS, Dept of Forestry, Florida Emergency Management, DoD bases including the U.S. Coast Guard, and various industries such as tourism, fishing, and agriculture.

There could be considerable synergy between this modeling project and several of the other projects discussed below.

2.2 Dual Polarization Radar

Dual polarization radar allows inference of the size, number, and species of hydrometeors (rain, snow, hail, graupel). Timelines of the vertical profiles of density of various hydrometeor species versus temperature are important in natural lightning, triggered lightning, downbursts, hail, rainfall, and perhaps tornadoes.

The utility of dual-polarization radar in lightning forecasting has been well documented, though not at the CCAFS/KSC locale or other coastal subtropical environments. But it is reasonable to assume it will work there too. The University of Central Florida is currently working to develop an operational technique to forecast the onset of lightning with dual-polarization radar (Kasparis, et al., 2002).

The utility of dual-polarization radar in downburst prediction makes good theoretical sense. However, only limited documentation exists on this particular aspect of dual-polarization radar. More work is needed to prove its utility, especially in the CCAFS/KSC locale.

The utility of dual-polarization radar in lightning LCC is a future possibility. Indeed, it has been suggested that the lightning LCC will eventually evolve into a single launch rule incorporating dual polarization radar products and surface field mill readings. But significant research comparing dual-polarization radar to in-situ cloud electrification measurements will be needed.

The current modified WSR-74C with Integrated Radar Information (IRIS) post-processor, a non-Doppler non-dual-polarization conventional radar, is being considered for replacement. Dual-polarization radar is a required purchasable option in the WSR-74C replacement contract. However, more evidence of the utility of dual-polarization radar in the local environment would be very useful in justifying that purchase.

2.3 Automated Weather Warning Dissemination

The weather warnings from 45 WS are relayed to outside workers via public announcement speakers via the Cape Support office. The workers sometimes have difficulty understanding the announcements. In addition, it can take several minutes for the announcements to be completed. An automated announcement system can greatly increase the clarity and speed of delivery. The distribution media can be a combination of PA announcements, large lighted public display boards, pager notifications, fax, phone, closed-circuit TV warning announcement screen, radio audio loops, etc. Similar technology has been used with tremendous success for years by the National Weather Service.

2.4 Fill Data Voids

Although 45 WS uses one of the most densely and most unusually instrumented weather networks in operational meteorology, there are still data voids that impact the weather support mission. In particular, there is very little weather data offshore. One possible solution is satellite soundings with more advanced retrieval algorithms. But data voids also include types of weather data. For example, there are no soil moisture data available operationally, which is known to affect the numerical model forecasts of sea-breeze onset. Likewise, there are no visibility sensors in the St. Johns River valley, just inland from CCAFS/KSC, which impacts fog forecasting. Partial fixes to the soil moisture and visibility problems are in-progress.

There is a synergistic interaction between this topic and the ‘extreme numerical modeling’ project. Filling data voids appropriately can yield improved numerical model performance. Simulation runs with denied real data and with synthetic observations can help identify what data voids are most cost-effective to fill. Innovative use of current weather data, especially from weather satellites, may help with some of these problems.

2.5 Integration And Display Of Weather Sensors

Modern meteorology has a plethora of disparate data sources available. This problem is compounded at CCAFS/KSC by the variety of local weather data. One method to deal with this problem is a system that integrates and displays the various weather sensors. This is especially true of non-traditional data such as satellite profilers, radar, and GPS-based precipitable water. The integration should be displayed in a simple, easily interpreted horizontal, vertical, and temporal display for use by operational forecasters. The system would also allow for the display of more than the basic meteorological variables (wind, temperature, and humidity), but also other operationally important variables such as cloud base and top, for LCC evaluation. The system should allow for “alarming” if any operational watch/warning threshold is approached, with enough “cushion” to allow for forecaster reaction time and meeting operational desired lead-time, should be flexible and set by the operators. The Applied Meteorology Unit (Ernst and Merceret, 1997) has developed the Local Data Integration System (Case, et al., 2001) which is a very basic version of this integration and display system.

2.6 Improved 50 MHz Doppler Radar Wind Profiler (50 DRWP)

The 50 DRWP provides rapid updates of upper-level winds. The updates are more frequent and more vertical than conventional RAOBs, but don’t have the same accuracy or vertical resolution. The 50 DRWP winds are used directly in ‘Loads’ decisions for some launch vehicles and indirectly for all others if a jet streak is detected entering/departing the area, which may not yet have been detected by RAOBs (Fitzpatrick, et al., 2000). 'Loads' refers to the aerodynamic loading on the rocket as it counter-steers against the winds to stay on trajectory to enter the correct orbit. The rocket can steer hard enough to destroy itself, if the actual winds are different enough from the planning winds. The 'Loads' community continually analyzes the most recent winds and will delay or scrub a launch as needed.

There are two main opportunities for improved 50 DRWP data. Improved digital signal processing can help better isolate the atmospheric signal from other competing signals. In addition, the current quality control support software is quite crude. Better interfaces and QC options will allow the human quality controllers to do a better faster job. An automated reliable QC software program could improve the 50 DRWP data during routine day-to-day operations and assist the human quality controllers during launch countdowns. A better manual interface for QC is planned under the Range Standardization and Automation contract, but the other improvements discussed above are still needed.

2.7 Air Force Institute Of Technology (AFIT) Weather Laboratory Upgrade

The Air Force Institute of Technology is one of the main sources for operational research to Air Force Weather. However, the computer workstations and tape readers in their weather laboratory restricts the amount of radar research they can perform. Unfortunately, many of the operational research projects 45 WS would like to do with AFIT consists of radar projects. These projects would emphasize lightning forecasting and downburst prediction. Other Air Force Weather organizations would also benefit from high-end workstations for the AFIT Weather Laboratory. This upgrade would be fairly inexpensive, costing ~$100K.

This project doesn't truly qualify as an "advanced weather project". However, it's an even worse fit to the other categories of 45 WS projects, and so is included here for completeness.

2.8 Cloud Radar

The 45 WS and SMG both have a need to detect clouds accurately, especially for evaluating lightning LCC and Flight Rules, respectively. A cloud radar, using sub-centimeter wavelengths, could improve cloud detection. Cloud radar can not replace weather surveillance radar since it attenuates severely with larger rain droplets and can not interrogate the structure of thunderstorms, which is vital for weather watches and warnings.

2.9 Global Positioning Satellite Based Precipitable Water (GPS-PW) Micro-Network

Global Positioning Satellite receivers, when combined with surface pressure measurement, can infer precipitable water in the atmosphere above them with excellent accuracy. GPS-PW technology is advancing rapidly. Soon line of sight measurements to individual GPS satellites should be possible. This in turn should allow moisture profiling, either directly and/or in conjunction with local numerical modeling (Gutman, et al, 2002). A micro-scale network of ~15 GPS-PW sensors across the CCAFS/KSC area should be able to provide time-series of the 3-D moisture fields. One GPS-PW sensor, owned by the U. S. Coast Guard, is already located on CCAFS.

Improved thunderstorm nowcasting should result from this micro-network of GPS-PW sensors, either through direct detection of moisture convergence and/or through local numerical modeling. One study at the University of Hawaii showed GPS-PW does have skill in forecasting thunderstorms at CCAFS/KSC (Mazany, 1999). If incorporated into numerical modeling, there is also possible benefit to cloud forecasting for SMG Flight Rules. New GPS-PW techniques will be needed, but those are being developed.

Given RSA plans to install the Local Area Prediction System (LAPS) at 45 WS, adding the capability to assimilate GPS-PW to LAPS would be a very cost-effective way to begin using GPS-PW for 45 WS. It has been estimated that this capability could be added to LAPS for under $100K.

2.10 Improved Lightning Launch Commit Criteria (LCC)

The Lightning LCC are the weather rules for avoiding natural and triggered lightning strikes to rockets during launch (Roeder, et al., 1999). The LCC are believed to be overly conservative since there is so much about atmospheric electricity and rocket triggered lightning that are not fully understood – operators must err on the side of safety. Various studies and field experiments can help refine the LCC to increase space launch opportunity while maintaining safety. Most recently, KSC funded a multi-year multi-agency field campaign using airborne field mills and in-situ cloud sensors, and special ground sensors to improve the 'anvil cloud' LCC and 'thick cloud' LCC (Merceret and Christian, 2001). Although this project could have large operational impact, it is ranked lower in priority since considerable work is already being done.

2.11 Automated Weather Forecast Advisor and Training Assistant

An automated weather advisor and training tool could provide three vital services to 45 WS forecasters: 1) reference guide, 2) training aid, and 3) forecast advisor. As a reference guide, the project would essentially be a Terminal Forecast Reference Notebook (TFRN) with interactive hyper-links and search function for easier faster look-ups. As a training aid, it would use the same information in the TFRN, but organized in sequential lessons with training exercises and scenarios and testing. As a forecast advisor, the program would use the same information, perhaps with access to the current observations, but with an intelligent front-end to guide the forecast process, with highly stratified climatology, internal application of all forecast tools, aid in identifying the forecast 'issue of the day' and perhaps automated drafting of the local forecast.

2.12 Launch Pad Lightning Warning System (LPLWS) Upgraded Display

The LPLWS is a network of 31 surface electric field mills in the CCAFS/KSC area. Timelines of the field mill readings are useful in determining if elevated readings are due to a set of known benign phenomena, which are not a threat to rocket triggered lightning or building electric charge in a developing thunderstorm. These timelines are currently provided by hardcopy strip-charts, which provide only a few ranges in which to display the data. Some values of electric field are either off the scale or too small to read the fine details on the next scale. In addition, side by side comparison of strip charts is useful in diagnosing the cause of the electric fields. But this can be difficult to do with the hardcopy, depending on which mills you want to compare.

On-screen electronic strip charts would be far superior. Automatic scaling would eliminate the display problem. The user should also be able to select a specific scale. The user should also be allowed to choose the specific mills they want to cross-compare, which would overcome that problem with the hardcopy.

Finally, LPLWS has a limited lightning detection capability. All types of lightning are detected but only the 2-D ground position of the center of electric charge change is plotted. A known deficiency is that lightning outside the network is sometimes detected and plotted erroneously on the edge of the network. Some research software has improved the lightning location capability and fixed the mis-plotting of off-site lightning, but that software would require considerable testing and rewrite before being implemented operationally.

2.13 Remote Sensing Electric Field Profiler

A device which can remotely sense and profile vertical electric fields aloft, including in clouds, would significantly improve the lightning LCC and increase safe launch opportunity. This sensor would replace 5½ of the current lightning LCC (Krider, et al., 1999). Unfortunately, this project is extremely high risk since new science will likely have to be developed.

3. SUMMARY

The agencies providing weather support to the space program in east central Florida face complicated weather support requirements, with a complicated suite of weather sensors, under complicated weather regimes. The advanced weather projects discussed here should significantly improve weather support to America's space program. The authors eagerly await discussion on possible routes for achieving these improvements.

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