6.1 DESIGNING WEATHER SUPPORT FOR FUTURE RANGES – RESULTS FROM THE ADVANCED RANGE TECHNOLOGY WORKING GROUP WEATHER SUBGROUP

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1. INTRODUCTION

The Advanced Range Technology Working Group (ARTWG) was formed to identify the technologies required for the best performing, most cost-effective future space launch and test Ranges, and the R&D required to achieve those technologies. The ARTWG resulted from a White House Office of Science and Technology Policy (2000) report on the future of America's space program. The White House tasked NASA and the U.S. Air Force to cooperatively identify the R&D requirements necessary to ensure the future competitiveness of U.S. ranges. Two parallel initiatives resulted, the ARTWG (2004) co-chaired by NASA and the Air Force, and the companion Advanced Spaceport Technology Working Group (ASTWG) (2003), chaired by NASA. At ARTWG's initial meeting in Jan 02, participants from DOD, NASA, industry, and academia resolved to build a consensus on the technology roadmaps required to improve the competitiveness of America's space program. America's share of the world's launch business had slipped from 80+% in the early 1990s to less than 50% a decade later. ARTWG divided into the following sub-groups: Meteorology; Command and Control; Communications; Planning, Scheduling and Coordination of Assets; Decision Making; Telemetry; and Tracking & Surveillance. ARTWG and ASTWG efforts were united under the Future Interagency Range and Spaceport Technologies program (FIRST) (2003) to plan, coordinate and leverage resources to build the future air and space transportation system. Meteorologists participated in their own sub-group as well as the Communications and Decision Making subgroups. The final reports of each Working Group, including the full details of the ARTWG Weather Subgroup technology roadmap, are available at the websites listed in Table-1. The roadmaps are intended to be living documents. The authors encourage further discussion and invite recommendations to update and improve the roadmaps.

TABLE-1. Final Reports.

WORKING GROUP	URL
ARTWG	http://artwg.ksc.nasa.gov
ASTWG	http://astwg.ksc.nasa.gov
FIRSTWG	http://firstprogram.ksc.nasa.gov

2. ARTWG WEATHER TECHNOLOGY ROADMAP

The ARTWG Weather Subgroup, which included government, industry and university participants, prepared a technology roadmap summarizing desired major capabilities for optimal meteorological support to space ranges for 25 years into the future. The 25-year planning time was further divided into three sub-periods (Table-2). The near term requirements can be met with technology that is currently available and implementation can begin immediately. The mid term requirements are those that will likely be available in 5-10 years or will require a small amount of development. The far term requirements are advanced capabilities that will require considerable time for research and development. Although the Weather Subgroup was under ARTWG, its roadmaps included both Spaceport and Range requirements.

TABLE-2. Main time periods within the 25-year planning period of the ARTWG Weather Subgroup.

NO.	TIME PERIOD	DATES
1	Near Term	2004-2009
2	Mid Term	2010-2015
3	Far Term	2016-2028

The ARTWG Weather Subgroup began building the technology roadmap by identifying six technology categories (Table-3). The first category of 'Weather Forecasts for Spaceport Operations' focused on improving the accuracy and timeliness of forecasts and warnings for 24/7 Spaceport and Range operations These operations include: 1) pre-launch ground processing (Boyd et al., 1995), 2) launch (Hazen et al, 1995), 3) post-launch, 4) special missions, and 5) round-the-clock weather warnings for personnel safety and resource protection. The second ARTWG category, Launch Commit Criteria (LCC) includes both the lightning LCC and User LCC. The Lightning LCC are a set of weather rules to avoid natural and rocket triggered lightning to launching rockets (Roeder et al., 1999a). The User LCC are the rules for low-level wind, ceiling, visibility, and precipitation for safe launch. The third ARFTWG category, Range Safety support (Boyd et al., 1999), includes weather inputs for toxic corridors (Parks et al., 1996), debris impact points, blast overpressure (Boyd et al., 2000), and radiological dispersion (Boyd et al., 2004). The fourth category, 'Recovery Forecasts', focuses on forecasts for reentry and descent through the Mesosphere and Stratosphere; and landing, both routine and emergency, anywhere in the world (Brody, 1997). The fifth category, 'Infrastructure and Personnel', emphasizes the organizational and personnel evolution required to safely reduce overhead costs and minimize the impact of the environment on

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future systems. Finally, the sixth category, 'Space Weather Forecasts', is concerned with the prediction of solar high-energy electromagnetic and particle radiation, which can damage sensitive electronics, harm astronauts, and degrade communications.

TABLE-3. Main technology categories identified as necessary by ARTWG Weather Subgroup.

NO.	TECHNOLOGY
1	Forecasts for Spaceport operations
2	Launch Commit Criteria
3	Range Safety support
4	Recovery Forecasts
5	Infrastructure and Personnel
6	Space Weather Forecasts

2.1 Special Features Of The Technology Roadmap

Some features of this roadmap deserve special mention. Weather support to the space program requires investment in the same basic technologies as the rest of Meteorology. Numerical modeling is a good example. Both normal meteorological and space launch meteorological support require improved models to describe and forecast the atmosphere's behavior. This includes not just better models but also proper data at sufficiently high temporal and spatial resolution to initialize the models. Also needed are computers with the speed and memory to process the data and run the models in sufficient time to be operationally useful, and communicate the results to decision makers. Thus, many elements in the roadmap are already in work or planned by the government, universities, and/or industry.

However, weather support to Range and Spaceport operations is so specialized that a separate weather technology roadmap is still needed. While support to pre-launch ground operations, launch, flight, re-entry and recovery/landing share many similar requirements with mainstream meteorology, a significant number are different with respect to criticality, impact of failure, accuracy, reliability, and/or spatial and temporal resolution requirements. For instance, forecast failure can cause major accidents during weather sensitive ground operations such as moving or loading of toxic fuels or explosives, resulting in loss or damage to expensive payloads and injury or possible death to personnel. Thus, in addition to the usual meteorological improvements already in progress, the weather roadmap for Spaceports also contains many technology needs unique to the space program, or technology needs common to the larger community but with different priorities.

These unique Space Program weather support requirements are driven by six main requirements:

1. Need to reduce the costs of providing weather support. For example, just the O&M costs of weather support to the Space Shuttle exceeds $2M per year. The sustainment costs add even more.

2. Need to reduce the impact of the environment on all operations: ground processing, launch, reentry, and landing. For examples, false alarms for lightning at the Cape Canaveral Spaceport cost several millions dollars/year in lost workforce productivity and even more in schedule delays; over 25% of launches are delayed or scrubbed because of violations of launch and flight weather rules, many of which are unnecessarily restrictive due to weather technology limitations;

3. Need to improve prediction and evaluation of rocket toxic dispersion, acoustic overpressure, debris fallout, and radiation dispersion to reduce the potentially catastrophic consequences of launch accidents on public safety, and improve launch opportunity

4. Criticality of staff meteorology involvement from "cradle to grave" in systems design, operations concept design, engineering studies, operations, in flight and post flight anomaly analyses, accident investigations, etc. Further discussion is provided below.

5. The space program has unique launch and landing requirements. For example, launch and landing rules to avoid triggered lightning. Further discussion is provided below. There are also stringent spatial and temporal resolution requirements for measurements and forecasts of upper level winds to ensure steering commands keep launch vehicles on the proper trajectory while not overstressing the vehicle.

6. New Spaceports are being planned. While most American launches still occur from Cape Canaveral Air Force Station/Kennedy Space Center, and Vandenberg AFB, other locations are beginning to charter and plan Spaceports in anticipation of increased opportunities if newer launch vehicles lower launch costs and increase space launch frequency. New Spaceports are being advocated in Alabama, Alaska, New Mexico, Montana, Virginia, Oklahoma, Texas, Utah, California, South Dakota, Nevada, Washington, and Wisconsin. Lowering weather support costs and reducing weather impacts through better forecasts and engineering/design consultation are keys to the success of these new Spaceports' plans and the ability of the American space launch industry to compete internationally. Mesoscale models will be needed which are tailored for both the unique forecast challenges and local weather infrastructure sensors available at these new Spaceports.

Given the challenges above, continued or even increased investment in new meteorological technology is necessary. Thus far, Space Shuttle program has funded much of the technology needed to satisfy the unique weather support requirements of America's space industry. As the Shuttle program is phased out by 2010, other funding sources will be required. Even if current weather quality was perfectly adequate, which it clearly is not (see #2 above), continued technology investment would be needed just to retain present support quality for America's space program. Otherwise rapid obsolescence of today's sensors, formats, data sources, hardware and software, etc. would degrade capabilities and support. In addition, models must be tailored to the local environment, operating systems kept current, and unique Spaceport/Range and launch vehicle requirements satisfied.

An example of just one weather support deficiency requiring technology development not otherwise required by the general meteorological community is triggered lightning, a significant and especially unique launch and landing hazard. Launch vehicle characteristics, long conducting body and ionized plume, 'magnify' an otherwise weak electric field to trigger lightning strikes. These rocket triggered lightning strikes can damage sensitive launch vehicle and payload electronics and cause catastrophic mission failure and/or destruction, as occurred with the Atlas Centaur 67 in March 1987.

Triggered lightning has been only sparsely researched. Estimating or measuring the presence of weak electric fields is very difficult; remotely measuring them, as is desired by the space program, is likely impossible. In addition, the magnification of the electric fields by the vehicle is poorly understood, as is the resultant field needed to trigger and sustain a lightning discharge. The distinction between natural and rocket triggered lightning is vital. It is not a problem just at thunderstorm prone areas like Florida. It's a threat anywhere/anytime there are clouds above the freezing level with sufficient thickness to produce a mix of water and ice. Thus, areas with low frequency of thunderstorms, like the Western Range at Vandenberg AFB on the central CA coast, and Kodiak Launch Complex in Alaska, are just as vulnerable as the Cape Canaveral Spaceport. Indeed, one study showed that Vandenberg AFB had a slightly higher scrub rate from the lightning launch commit criteria (LCC) than Cape Canaveral Spaceport (Roeder et al., 1999b). The numerous measurement and theoretical uncertainties associated with triggered lightning lead to very restrictive lightning LCC. Consequently triggered lightning LCC cause more launch delays and scrubs than any other weather phenomena, except perhaps upper level winds. Significant research is required to better measure and model the formation, magnitude, vertical and horizontal extents, and decay rates of electric fields aloft; determine electric field magnification as a function of vehicle; understand electric field breakdown; and develop safe, less restrictive, vehicle specific LCC.

To optimally leverage the benefits of technology development and reduce costs, critical organizational initiatives are necessary: an experienced cadre of meteorologists, formal technology transition unit(s), weather hubs, and space-based weather sensors. Discussion:

The Space Industry's unique requirements and its small base of experts, who tend to remain and work together for lifetime careers, emphasize another critical requirement of the Roadmap—an experienced cadre of professional meteorologists who provide expert support to each space system during its entire lifetime, from womb to tomb. Space customers can benefit from every incremental improvement to weather support accuracy, precision, and timeliness. However, the support's value diminishes if it's not properly applied. Experienced meteorologists, who work with their customer on a daily basis over a long period of time, can determine precisely who needs what support, when, and with what priority. They ensure the support is properly tailored and applied to specific customers, and the risks and limitations are properly assessed and communicated. Experience and an advanced degree in Atmospheric Sciences are mandatory long before a new system ever begins operations: during the design of space systems and their concepts of operation; in launch site selection; and in the design, procurement, and implementation of the weather infrastructure components necessary to support operations. The support is also critical during post operations engineering studies, anomaly analyses, and accident investigations.

In order to take advantage of and leverage technologies developed by NOAA, NCAR, universities and industry, and tailor them to support local Spaceport ground processing and launch & landing requirements, America's space industry must retain and increase a robust technology transition capability. The National Research Council recommended NASA create an Applied Meteorology (AMU), which occurred in 1991 under a tri-agency agreement between NASA, the Air Force Eastern Range, and National Weather Service, and has been a tremendous success (Bauman et al., 2004) (Ernst and Merceret, 1995). The AMU's activities include technology evaluation and development, as well as transition. The AMU's charter should be expanded to cover existing Spaceports such as Vandenberg, Wallops, and Kodiak, and others as they become active. Critical (AMU) features of the capability should include: co-location with operations; activities restricted to bridging between, but not including, pure research or operations; and work only on projects specifically tasked by its customers.

As the number of Spaceports expands, forecast functions should be centralized into weather hubs as much as possible to reduce costs. However a few meteorologists, preferably with advanced degrees, should still be located at each Spaceport to provide tailored local support, determine daily and long term support requirements, help design operations concepts that minimize the impact of the environment on schedule and cost, ensure weather infrastructure is properly maintained and sustained, etc. The interpersonal relationships and confidence building that occur between the meteorologist and management from this daily interaction are critical on launch day as the launch team makes crucial decisions (rollout, tanking, launch, etc.) based on the forecasts and risk assessments from the meteorologist. Meanwhile, the hubs can provide multiple Spaceports the routine 24/7 warning and advisory support needed for resource protection.

Another cost saving to the American space program as a whole would be to increase the number of space based weather sensors that could serve multiple Spaceports and reduce as much as possible the need to O&M and sustain a network of local sensors at each Spaceport. Since the Spaceports would be managed by diverse entities such as the Federal government, State governments, Federally Funded Research & Development Centers, or industry, advocating and funding the space-based sensors which satisfy a common need would require special agreements and cooperation to advocate the systems and arrange funding and/or share funding.

Coordinating efforts and building consensus for mutually beneficial activities such as technology development and shared resources, is easier for weather systems than other space program technologies. The reason is the atmospheric sciences already enjoy a cooperative, integrated, professional community. Government agencies, industry, and academia have a well established history of cooperation, integrated efforts, and synergy. Several professional organizations already exist which can facilitate the building of consensus and advocacy (American Meteorological Society, National Weather Association, American Institute of Aeronautics and Astronautics, American Geophysical Union, etc.). However, leadership is still necessary to take advantage of this valuable resource. The ARTWG Weather Subgroup itself is an example of this cooperation within the meteorological community. The ARTWG Weather Subgroup examined a large range meteorological disciplines. Many experts from many organizations teamed to prepare the technology roadmap. This team is gratefully acknowledged in Table-4. (Note: "organization" refers to that at time of involvement with the ARTWG, and may not be current)

2.2 Available Technologies of Special Note

Two technologies are immediately available that would provide significant improvement to Range operations, if funding were available. The weather Warning Decision Support System-Integrated Information (WDSS-II) has been developed by NSSL (Hondl, 2003) and has begun operational use at some locations. The WDSS-II has the excellent weather warning decision assistance algorithms and displays of the first generation WDSS, plus has been improved to better facilitate the research and development of locally tuned products, and the integration of other weather sensors. The WDSS-II is especially good at integrating data from multiple weather radar sites. These very fast updates would be useful to launch operations at Spaceport Florida given their frequent thunderstorms, sensitivities to convective winds and the availability of the nearby WSR-74C at Patrick AFB, WSR-88D at NWS/Melbourne, and even the TDWR at Orlando airport. Integration of the dense network of local weather sensors at Spaceport Florida would also prove beneficial (Harms et al., 1998).

The second immediately available significant technology is improved dissemination of weather warnings at Spaceport Florida. A system that would take the input from the meteorologist and automatically create and disseminate the warnings to multiple local sites via multiple display media would greatly improve the current process. Similar technology has been used by the NWS for many years.

Additionally, funding has been requested to take advantage of recent improvements in weather surveillance radar technology.

TABLE-4. Members of ARTWG Weather Subgroup.

PERSON	ORGANIZATION
John Madura (Co-Chair) (NASA lead)	NASA Weather Office
Rick Heuwinkel (Co-Chair, Jan 02-May 03)	Federal Aviation Administration (FAA)
Joann Ford (Co-Chair, May 03-Oct 03)	FAA
Karen Shelton (Oct 03-Present)	FAA
William Roeder (Air Force lead)	45th Weather Squadron (45 WS)
Wade Batts	Marshall Spaceflight Center
Philip Bennardo	Kennedy Space Center (KSC)
Bob Borchers	Science Applications International Corporation (SAIC)
Elizabeth Borelli	30th Weather Squadron
Billie Boyd	45 WS
Christine Boykin	Johnson Space Center (JSC)
Frank Brody	JSC
Jeppe Compton	All Points Logistics
Pete Conant	Boeing
Bob Crisler	Lockheed Martin
Al Dianic	Ensco Inc
Anthony Guiffrida	SAIC
Dewey Harms	45 WS
Harold Herring	Computer Sciences Raytheon (CSR)
Terry Huck	White Sands Missile Range
Phillip Krider	Univ. Arizona
Michael Maier	CSR
John Manobianco	Ensco Inc.
Pedro Medelius	Arctic Slope Research Corp.
Frank Merceret	KSC
Cindy Mueller	National Center for Atmospheric Research
Glenn Overbey	Glenn FAA
Bud Parks	ACTA Inc
Barry Roberts	Marshall Spaceflight Center
Dave Sharp	National Weather Service/Melbourne
Darin Skelly	KSC
Dave Smarsh	National Oceanic Atmospheric Administration (NOAA)
Al Sofge	Headquarters NASA
Christine Stevens	Aerospace Corp.
Greg Taylor	Ensco, Inc.
Maria Tobin	KSC
Marty Waldman	Air Force Space Command
Kurt Warner	CSR
Mark Wheeler	Ensco, Inc.
Dan Wolfe	NOAA
Neil Wyse	45 WS
Wilson Jim	NCAR

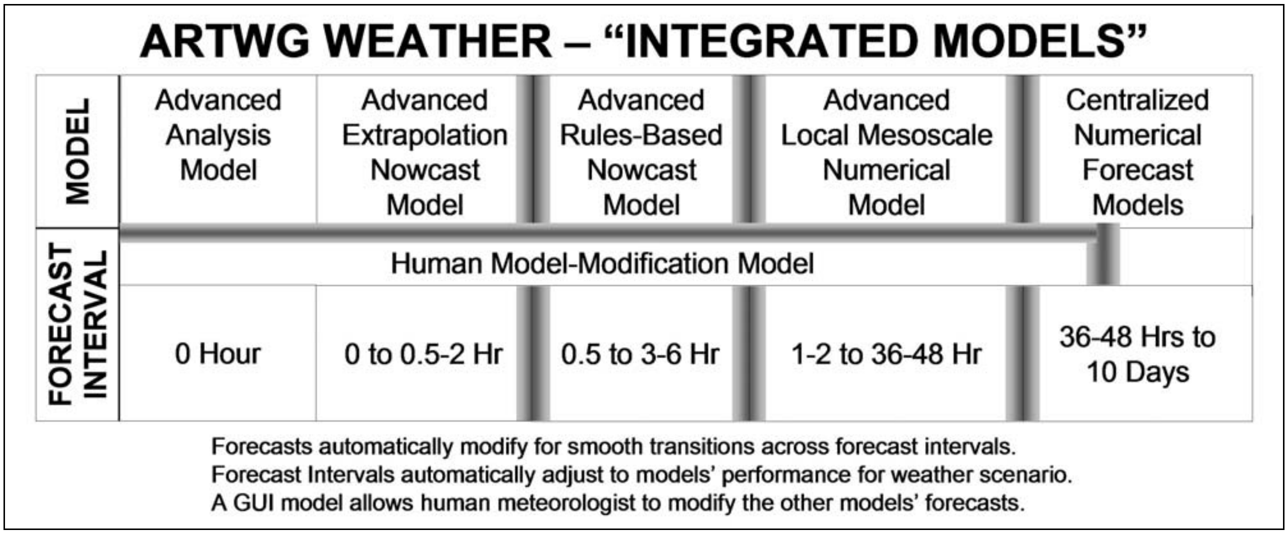
Many of the ARTWG subgroups proposed high-altitude long-dwell Unpiloted Aerial Vehicles (UAV) and/or High-Altitude Air Ships (HAAS) for future use as various communication and sensor platforms. In essence, the UAV/HAAS act as psuedo-satellites, giving a constantly available platform with long line-of-sight, but without the high costs of orbital satellites. The proposed weather uses are profiling of temperature, moisture, and wind. A UAV/HAAS platform has several advantages over traditional weather satellites. Geostationary weather satellites give continuous view over any particular area but low-resolution soundings due to their high altitude orbit. Polar weather satellites give higher-resolution sounding, due to their low orbit, but typically only provide two local views per day. A UAV/HAAS could provide even higher-resolution than polar satellites, but with continuous view of the local area, as provided by geostationary satellites. However, the sensor platforms would need to be developed and numerical models modified to assimilate that data with a new vertical density and time frequency, as compared to other weather data.

The ARTWG weather subgroup has also proposed a system of advanced integrated models (Figure 1). The system begins with an advanced locally tuned analysis model that assimilates non-traditional weather data, especially from dense local networks. Very short nowcasts (0 to 0.5-2 hours) are provided by an advanced extrapolation model. Somewhat longer nowcasts (0.5 to 3-6 hours) are provided by an advanced rules-based model. Short-term forecasts (1-2 to 36-48 hours) are provided by an advanced local mesoscale model. It is important to note that this local mesoscale model would need very high resolution, soil moisture measurements, and advanced air-sea interaction modeling to handle the subtle convection at Spaceport Florida. The local mesoscale model would also provide some optimal combination of blending, nudging, and ensemble forecasts. Longer-range forecasts (36-48 hours to 10 days) would be provided by the centralized national numerical models. The integrated models system has two other important features. The human meteorologist can override and adjust any the models from analysis through short-term forecasts. A separate GUI-based model would be needed to provide this function. The transitions between forecast intervals would need to be seamless to avoid discontinuities as the final forecast is created by different models. In addition, the forecast intervals themselves should be flexible, automatically adjusting to the complexity of the weather scenario to provide the optimal forecast. For example, if the current storm paths were very complicated or variable, the extrapolation model would transition to the rules-based model sooner than normal. This integrated models system would obviously require considerable research and development, but is the key to the highest quality weather support in the long-term future. The authors now call this system ‘integrated models’, as opposed to ‘blended models as in the original technology roadmap, to avoid confusion with ‘blending’ which is an unrelated technique in local mesoscale modeling.

Finally, a vitally important long-term need is for determination of electric-field profiles in clouds. This is expected to greatly reduce the operational impact of the lightning LCC. Unfortunately, new science will likely have to be created to make this possible, so the technical feasibility is doubtful. However, the operational return would be considerable, so high-risk/high-return R&D pursuing this capability may be justified.

4. SUMMARY

The ARTWG Weather Subgroup created a technology roadmap for optimal weather support to Spaceports and Ranges for the next twenty-five years. The authors invite further discussion and no-cost proposals on fulfilling this technology roadmap.



ARTWG WEATHER – “INTEGRATED MODELS”

MODEL	Advanced Analysis Model	Advanced Extrapolation Nowcast Model	Advanced Rules-Based Nowcast Model	Advanced Local Mesoscale Numerical Model	Centralized Numerical Forecast Models
FORECAST INTERVAL	Human Model-Modification Model				
	0 Hour	0 to 0.5-2 Hr	0.5 to 3-6 Hr	1-2 to 36-48 Hr	36-48 Hrs to 10 Days

Forecasts automatically modify for smooth transitions across forecast intervals.
Forecast Intervals automatically adjust to models’ performance for weather scenario.
A GUI model allows human meteorologist to modify the other models’ forecasts.

Figure 1. ARTWG ‘integrated models’.

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