Launch Weather Decision Support System

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1. Identification and Significance of the Innovation

1.1 Executive Summary

Launch safety and efficiency requires timely and accurate wind, thermodynamic and pressure information from the surface to 20 km height, and lightning risk identification. A Doppler radar now provides wind measurements that satisfy this requirement at the Eastern Test Range. Thermodynamic soundings are provided by intermittent radiosondes on launch day. Typically a radiosonde takes an hour to reach altitude and may drift distances of 100 km or more at 20 km height. These facts limit radiosonde timeliness and accuracy in characterizing the atmosphere along the launch path. NASA is seeking a thermodynamic remote sensing system that better represents the atmosphere along the launch trajectory and provides accurate, timely data in clear and cloudy conditions. Current Radiometrics (RDX) microwave radiometer profilers provide continuous thermodynamic profiles from the surface to 10 km height, with radiosonde equivalent accuracy up to several km height, with decreasing accuracy at higher levels. The RDX profiler also provides cloud and atmospheric stability information that can be used to identify lightning risk. Improved thermodynamic profiler accuracy, and pressure profiling capability, have been demonstrated using variational retrieval methods that include model gridded analysis[1]. Variational retrievals can also extend accurate thermodynamic and pressure profiling to 20 km height. We propose to implement and automate variational retrieval and lightning risk identification methods in a Launch Weather Decision Support System. The LWDSS will provide timely and accurate thermodynamic, pressure and lightning risk information needed to improve launch and airport safety and efficiency.

1.2 Space Launch and Weather

Space launch activities can be divided into two broad categories – ground processing and launch processing. Launch processing, especially Day of Launch (DOL) activities, are certainly the most visible and arguably the most dangerous phase. However, when considering overall costs and schedules, ground processing activities are significant. Many of these activities, such as vehicle assembly and testing, and propellant loading, are vulnerable to weather conditions. Daily quantification and accurate timing of threats from lightning, heavy precipitation and high winds are important for scheduling, as well as personnel and resource protection.

Launch operations, and landing operations, are strongly affected by atmospheric and environmental conditions. Every vehicle design has physical limits that restrict acceptable launch conditions. As a vehicle accelerates after launch, dynamic pressures peak at an altitude where atmospheric density and vehicle speed produce maximum dynamic pressures (max Q) – usually at 10-12 km in altitude. Thus, part of the launch decision process must consider the vehicle steering program, the DOL wind profile, and atmospheric density profile. In addition to vehicle loads analyses, some weather conditions must be evaluated before launch to protect the vehicle from triggered and natural lightning. Important factors in these evaluations are cloud temperatures and liquid content near the vehicle trajectory. Finally, the safety of personnel performing launch preparations must be protected from lightning and toxic dispersion while minimizing impact on the launch schedule. As shown in Figure 1, weather has high Impacts both to launch scrubs as well as launch delays accounting for nearly half of launch scrubs and 30% of launch delays.

1.3 Radiosondes

Currently, wind, temperature, humidity and pressure soundings are observed by several rawinsondes on launch day (DOL). These soundings are then used to model vehicle atmospheric stress and to help characterize lightning risk. Radiosonde data are used to characterize local wind, temperature and humidity profiles. However, they have some

[1] Ware, R., D. Cimini, E. Campos, G. Giuliani, S. Albers, M. Nelson, S. Koch, P. Joe, and S. Cober, Thermodynamic profiling during the 2010 Winter Olympics, Atmos. Res., 2013.

limitations. In addition to being manpower intensive, the balloons drift with the wind and as shown in Figure 2, they may be 100 km or more downwind at max Q altitudes. The resulting uncertainty in characterizing atmospheric conditions along the vehicle launch path can reduce launch availability.

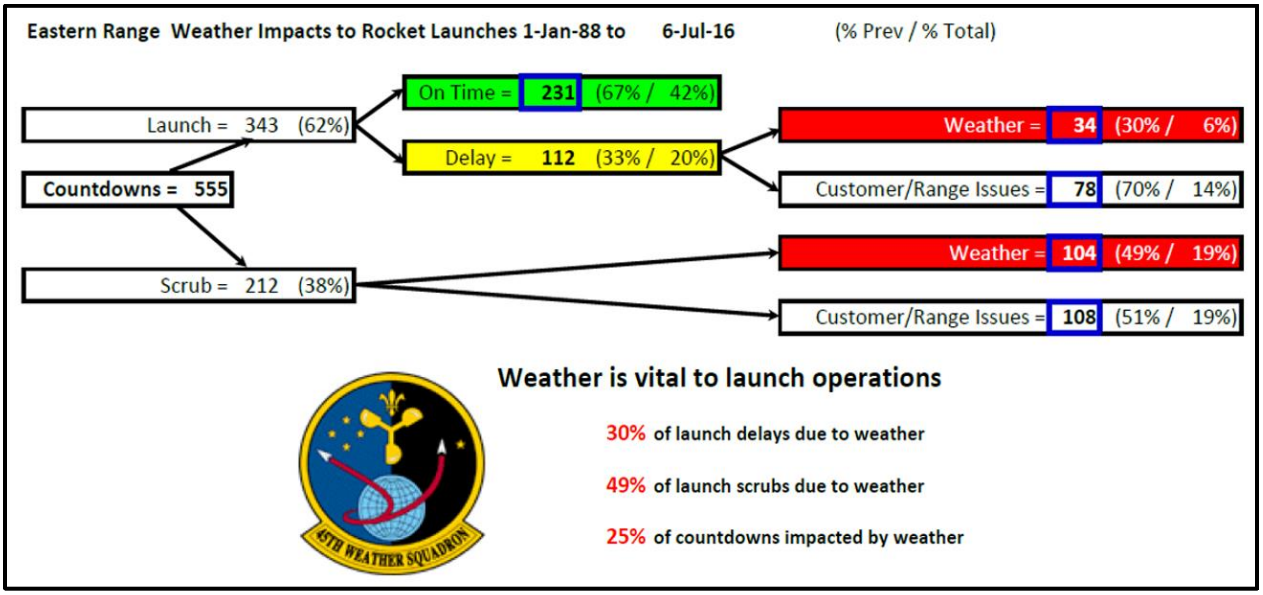

Figure 1. Weather impacts to DOL activities at the Eastern Range.
Compiled by the 45th Weather Squadron, Patrick AFB, FL.

1.4 Microwave Thermodynamic Profilers

The RDX Microwave Thermodynamic Profiler (MTP) product (Figure 3) uses neural networks (NN) to retrieve temperature, humidity and liquid profiles to 10 km height. The NN are typically trained using five years of historical radiosonde soundings. NN training includes creation of artificial liquid profiles at heights where the radiosonde humidity profile approaches saturation. Molecular emission and radiative transfer equations are applied to each radiosonde sounding to estimate the microwave brightness temperatures[2] that would be observed at ground level by each of the 35 MTP frequency channels[3]. The NN retrieve temperature, humidity and liquid profiles by correlating observed brightness temperatures with forward modeled brightness temperatures from several years of historical radiosonde soundings from the same site or a site

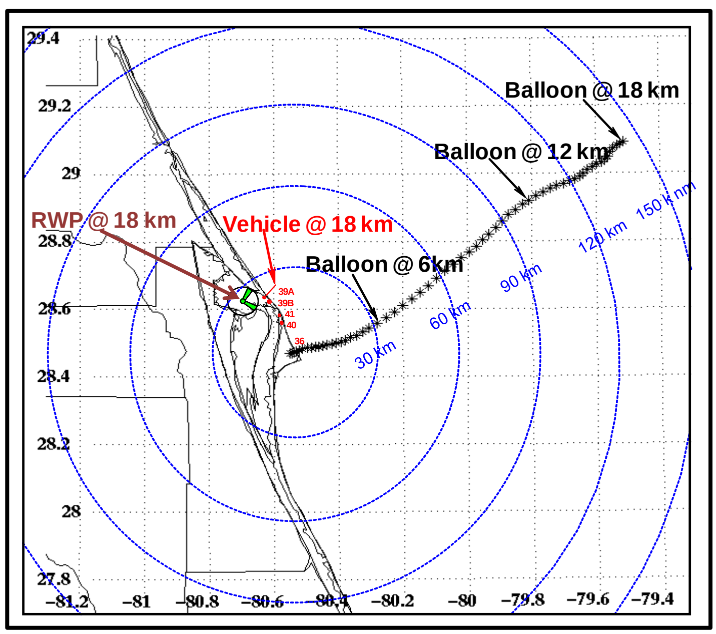

Figure 2. Example winter balloon and vehicle trajectories.

[2] Planck's law is applied to convert microwave energy to brightness temperature.
[3] 21 K-band (22-30 GHz) and 14 V-band (51-59 GHz) channels.

with similar climatology[1].

A schematic diagram of the RDX MTP passive atmospheric microwave observation spectrum is shown in Figure 4. A block diagram showing microwave energy conversion to temperature, humidity and liquid profiles is shown in Figure 5.

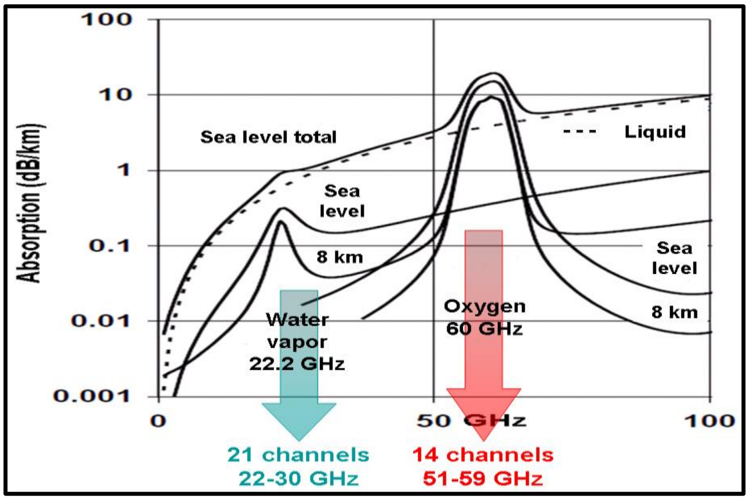

Figure 4. Atmospheric microwave spectrum.

Figure 3. RDX Microwave Thermodynamic Profiler.

RDX MTP products use NN to retrieve continuous temperature, humidity, and liquid water soundings to 10 km height in clear and cloudy conditions. More than 200 RDX MTP are now in use worldwide. Several of these MTP are integrated with radar wind profilers to support airport operations.

Example MTP temperature, humidity and liquid soundings at Frisco, Texas, on 5 Dec 2016 are shown in Figure 6. Liquid profiles seen in the bottom panel extending to ground level from 21 to 2230Z are consistent with the occurrence of rain showers.

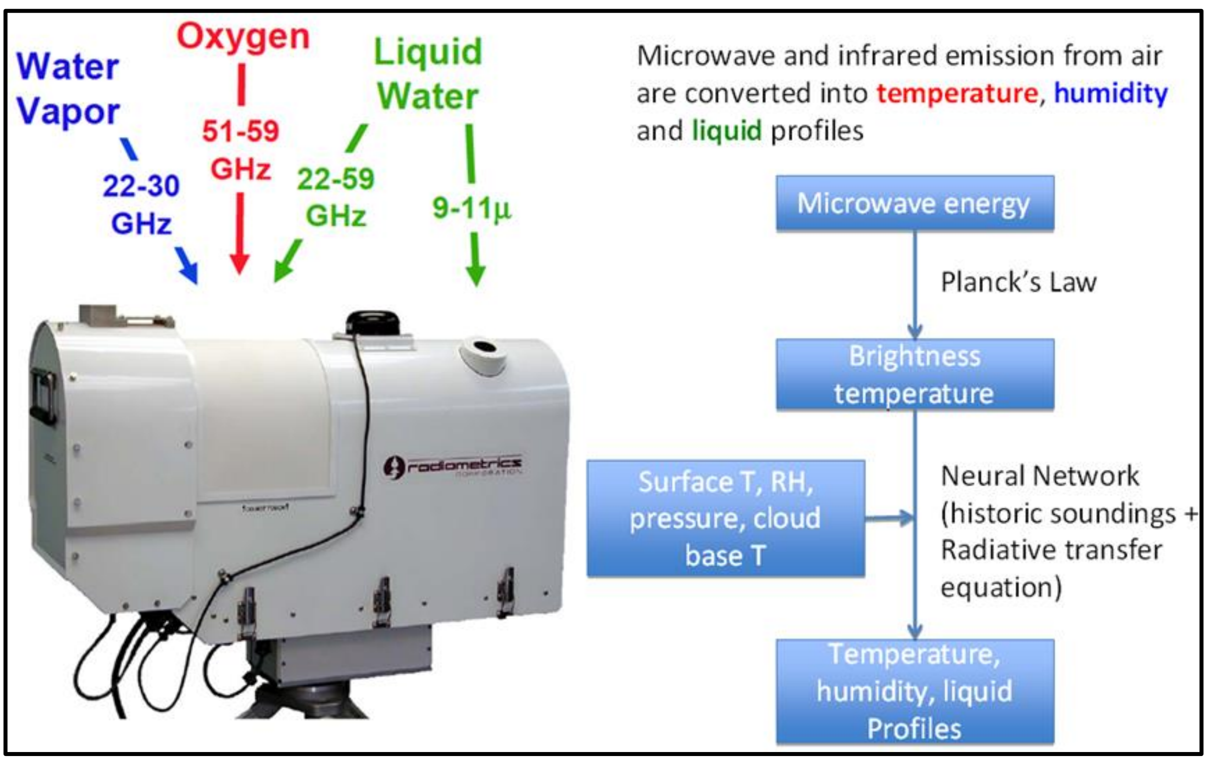

Figure 5. MTP profile retrieval schematic diagram.

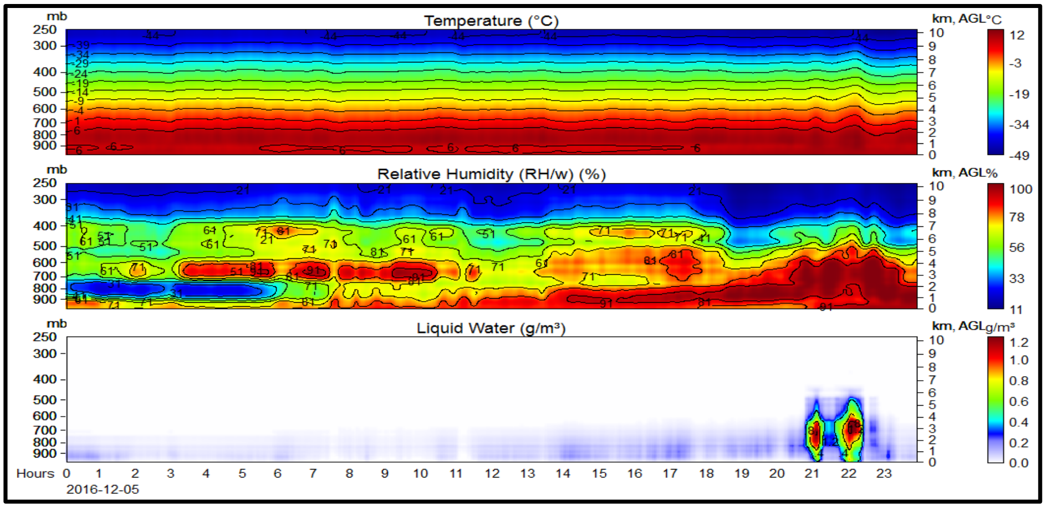

Figure 6. RDX MTP temperature, humidity and liquid soundings at Frisco, TX, 5 Dec 2016.

MTP temperature and humidity profile accuracies can be determined by comparison with radiosondes. A radiosonde (RS) launch site is located at Ft. Worth, Texas, 40 km from the Frisco MTP. One-dimensional variational retrievals (MTP 1DVAR) combining MTP and model gridded analysis[4] are compared with the Ft. Worth RS in Figure 7 (a). The RS dewpoint sounding (red dashed lines) shows significant variations that are smoothed by radiosonde observation error[5] in the MTP 1DVAR retrievals.

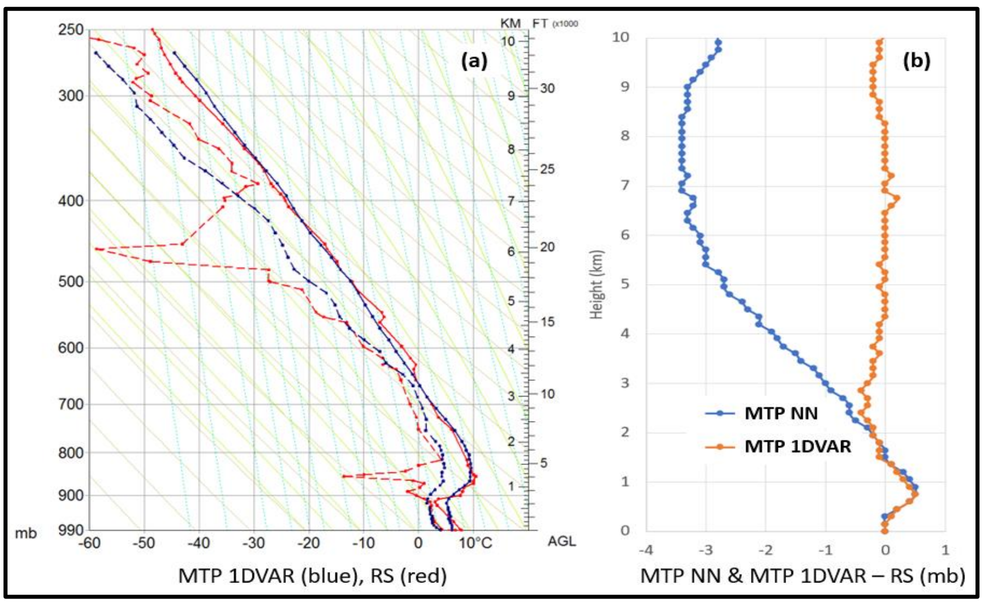

Figure 7. (a) MTP 1DVAR and radiosonde temperature (solid) and dewpoint (dash), (b) MTP NN and MTP 1DVAR minus radiosonde pressure.

[4] Hewison, T., Temperature and 1D-VAR retrieval of temperature and humidity profiles from a ground-based microwave radiometer, TGRS, 2007.

[5] Radiosonde observation error is dominated by representativeness error, the error in characterizing a model cell volume by a radiosonde point measurement along an uncontrolled flight path. Radiosonde Observation Error, RDX TechNote, 2015.

Good agreement is seen between the radiosonde and MTP NN pressure profiles to 2 km height (<3.5 mb), and between the radiosonde and MTP 1DVAR to 10 km height (<0.6 mb), even though the MTP site and the radiosonde launch site are separated by 40 km.

1.5 Radar Wind Profiler

Wind profile remote sensing to 20 km height is currently provided by a 48 MHz Radar Wind Profiler (RWP) at the Eastern Test Range; similar capability is planned for the Western Test Range. Figure 2 shows a common wintertime balloon versus vehicle trajectory at the Eastern Range. A jimsphere or standard rawinsonde rises at approximately 5 ms^{-1}. Thus, when the balloon reaches max Q altitudes 20-30 minutes after release, it may be 100 km or more downwind from its launch location. As shown in Figure 2, the RWP provides measurements much closer to the vehicle trajectory. Further, the RWP operates unattended 24x7 producing wind soundings every 5 minutes.

2. Technical Objectives

The technical objectives of the proposed LWDSS are to provide the following profiles to 10 km height at 150 m height intervals in clear and cloudy conditions in near real time:

- Temperature
- Humidity
- Pressure

The LWDSS will also provide the following information relevant to pre-launch triggered lightning evaluations during cloudy and partly cloudy conditions:

- Liquid Water Path (LWP)
- Cloud Base Temperature (CBT)
- Cloud Base Height (CBH)

In addition, the LWDSS will generate time series of stability indices and other parameters that can be used to identify natural lightning risk hours in advance of electric field mill methods.

The existing 48 MHz RWP at the Eastern Test Range provides 150 m height interval wind profiles from 2 to 20 km height. The LWDSS will include capability to integrate RWP and MTP profiles, providing continuous radiosonde-like soundings at the LWDSS location. This capability will increase launch operations safety and efficiency, and reduce launch operation costs.

2.1 Pressure Profiles

Current RDX MTP NN retrieval methods provide minute-by-minute temperature, humidity and liquid profile retrievals in clear and cloudy conditions to 10 km height. Pressure profiles can be calculated from the temperature and humidity profiles, and surface pressure, using the hypsometric equation[6]. MTP 1DVAR and radiosonde (RS) temperature and dewpoint profile retrievals are shown in Figure 7 (a). Differences between pressure profiles derived from MTP NN and MTP 1DVAR retrievals, and observed by the radiosonde (launched 40 km away from the radiometer), are shown in Figure 7 (b). Pressure profiles calculated from MTP NN retrievals show good agreement with radiosonde pressure profiles to 2 km height. Good agreement is extended to 10 km height using MTP 1DVAR retrievals.

[6] Wallace and Hobbs, Atmospheric Science, An Introductory Survey, 2009.

2.2 20 km Profile Heights

Pressure profiles calculated from MTP NN retrievals show good agreement with radiosonde pressure profiles to 2 km height. Good agreement can currently be extended to 10 km height using MTP 1DVAR retrievals. We propose to develop MTP 1DVAR temperature, humidity and liquid retrievals to 20 km height. Pressure profiles calculated from these retrievals are expected to provide good agreement with radiosonde pressure profiles to 20 km height.

2.3 150 m Profile Height Intervals

MTP 1DVAR methods can provide profile retrievals with 150 m height intervals. We propose to develop LWDSS code with this capability. This feature will match MTP 1DVAR with existing wind radar height intervals at the Eastern Test Range, allowing wind, thermodynamic, pressure and liquid profiles with identical height intervals from the surface to 20 km height.

2.4 Lightning Risk Identification

The India Space Research Organization (ISRO) reported that MTP observations can be used to identify lightning risk more than two hours in advance of traditional methods using electric field mills (EFM)[7]. ISRO analyzed collocated MTP and EFM observations during 26 thunderstorms, and found sharp changes in MTP-derived stability indices hours in advance of EFM lightning alerts. They applied an algorithm based on composite temporal variations of the indices to nine independent thunderstorm cases and identified lightning risk at least two hours in advance of EFM methods in all cases (Figure 8).

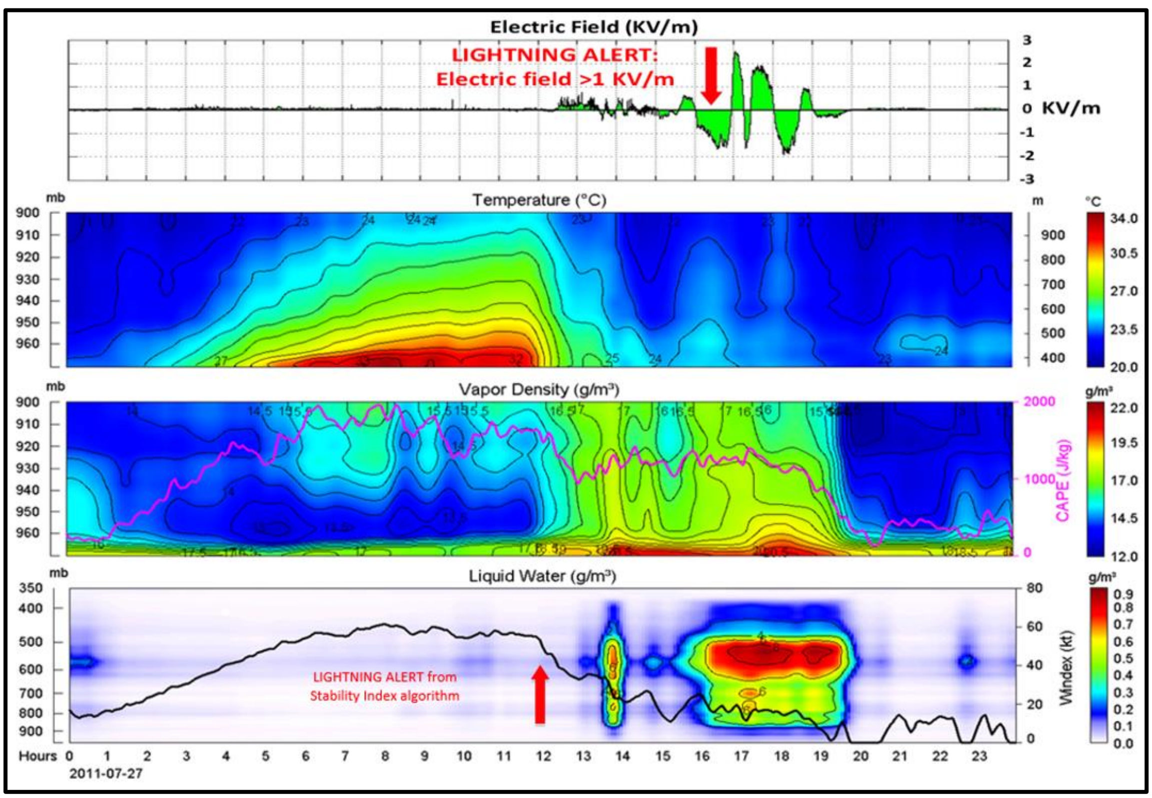

Figure 8. Example MTP lightning risk identification more than two hours in advance of an Electric Field Mill.

[7] Madhulatha, A., M. Rajeevan, M.V. Ratnam, J. Bhate and C.V. Naidu, Nowcasting severe convective activity over southeast India using ground-based microwave radiometer observations, JGR, 2013.

Key Launch Commit Criteria (LCC) parameters during cloudy conditions include the presence of liquid water, cloud temperature, and cloud thickness[8]. Example time series of related MTP-derived parameters are shown in Figure 9. Cloudy conditions prevailed for the entire day. For this example, the MTP data would have allowed relaxation of LCC restrictions to widen the launch window by 200%. Specifically, liquid water path (LWP) values were less than the 0.1 mm radiometer LWP detection threshold from 1:00 to 13:30 Z. During this time, cloud base temperature ranged from 3 to -60 C, and cloud base height from 800 m to 9.3 km, indicating the presence of supercooled cloud and associated lightning risk. However, since liquid water was not detected during this period, LCC restrictions could have been relaxed.

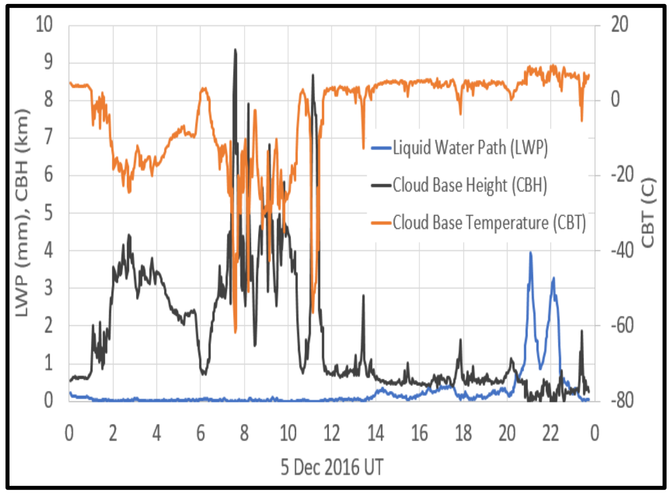

Figure 9. MTP liquid water path, cloud base height and cloud base temperature.

2.5 Launch Weather Decision Support System (LWDSS)

The proposed LWDSS will provide near continuous wind, thermodynamic and liquid soundings to 20 km height in cloudy and clear conditions. These soundings will provide timeliness and accuracy better than intermittent radiosonde measurements along uncontrolled flight paths. In addition, stability indices and other atmospheric parameters derived from LWDSS data can identify lightning risk hours in advance of traditional electric field mill methods. The LWDSS also provides liquid water, cloud base temperature and cloud base height information that can be used to relax triggered lightning launch restrictions during cloudy conditions.

3. Phase I Work Plan

The Radiometrics and CAPS team has the technical and management expertise needed to successfully develop a Launch Weather Decision Support System that will improve launch processing safety and launch availability, thereby reducing the cost of access to space.

3.1 Scope

The proposed effort consists of a 9-month prototype LWDSS design and evaluation. Deliverables include a kickoff meeting, monthly reports, technical reviews and a final report. The program is divided into six tasks, described below.

3.2 LWDSS Features

We propose to develop the LWDSS including features described in the following subsections.

3.2.1 Feature Analysis and Refinement

Under this task, the RDX-CAPS team will coordinate with launch range and aviation experts to develop, analyze and refine LWDSS features to quickly define a baseline system strategy and optimize hardware and software

[8] Merceret, F., M. McAleenan, T. McNamara, J. Weems and W. Roeder, [Implementing the VAHIRR Launch Commit Criteria using Existing Radar Products](), ARAM, 2006.

requirements. Wind radar integration into the LWDSS will be considered.

3.2.2 Pressure Profile Code Development

This task includes development of code that calculates pressure profiles from the MTP surface pressure measurement, and the temperature and humidity profile retrievals. Resulting pressure profile accuracy will be evaluated by comparison with radiosonde pressure profiles at additional subtropical locations.

3.2.3 20 km Height Profiles

RDX MTP products retrieve temperature and humidity profiles using NN trained with several years of historical radiosonde soundings. Molecular emission and radiative transfer equations are used in NN training to forward model microwave brightness temperatures that would be observed at ground level by each of the 35 MTP frequency channels[9]. In simple terms, the NN retrieves temperature and humidity profiles by correlating observed brightness temperatures with forward modeled radiosonde brightness temperatures.

3.2.4 150 m Profile Height Intervals

Current MTP 1DVAR profile height intervals are 250-m or less. We propose to develop MTP 1DVAR code that provides 150 m profile height intervals. This will match profile height intervals of the existing 48 MHz RWP in operation at the Eastern Test Range.

3.2.5 Lightning Risk Algorithm

Forecast index time series derived from RDX MTP temperature and humidity measurements provide lightning risk identification hours in advance of traditional electric field mill methods[6]. The MTP also measures liquid water path (LWP), cloud base temperature (CBT) and cloud base height (CBH), parameters that contribute to natural and triggered lightning risk Launch Commit Criteria (LCC)[5]. We propose to evaluate and refine lightning risk identification algorithms based on MTP-derived forecast indices[10] and LWP, CBT and CBH.

3.2.6 Integrated Wind and Thermodynamic Profiles

The existing RWP at the Eastern Test Range provides wind profiles to 20 km height with 150 m height intervals. LWDSS thermodynamic profiles will be delivered with the same height intervals. We propose to develop LWDSS code that integrates wind and thermodynamic profiles. The full suite of traditional forecast tools and indices can be generated as time series from these integrated profiles. Additional local high impact weather risk identification and mitigation capabilities may emerge from these unique time series. We propose to explore and evaluate forecast index time series high impact local weather forecast applications.

3.3 Technical Approach

We will further evaluate the LWDSS delivering MTP 1DVAR temperature, humidity, liquid and pressure soundings. The LWDSS will extend variational sounding heights beyond 20 km height with 150 m vertical resolution. We will also develop an automated lightning risk identification system using MTP 1DVAR-derived K index, humidity index, precipitable water, stability index and equivalent potential temperature lapse rate time series. We will validate MTP 1DVAR temperature, humidity and pressure soundings via rigorous statistical rawindsonde comparisons in a subtropical environment, and evaluate lightning risk identification accuracy via rigorous statistical comparison with

[9] 21 K-band (22-30 GHz) and 14 V-band (51-59 GHz) channels.

[10] Cimini, D., M. Nelson, J. Güldner and R. Ware, Forecast indices from ground-based microwave radiometer for operational meteorology, AMT, 2015.

lightning detection network data.

3.4 Task Descriptions

The RDX team includes atmospheric scientists (Wilfong and Reed) with extensive launch range experience (Wilfong), and a physicist (Ware), with extensive experience in atmospheric remote sensing via microwave radiometry (Ware and Reed) and RWP (Wilfong), will conduct the following tasks during Phase I:

The University of Oklahoma CAPS[11] team includes meteorologists with extensive experience in numerical weather modeling. They will validate MTP 1DVAR temperature, humidity and pressure soundings via rigorous statistical comparison with radiosondes in a subtropical environment. CAPS will also evaluate lightning risk identification accuracy via rigorous statistical comparison with lightning detection network data.

4. Task Labor Categories and Schedules

Task labor categories for the RDX and CAPS investigators are described in the following subsections. The tasks are scheduled for completion six months after kickoff, followed by Phase II proposal preparation.

Table 1. The proposed Phase I work plan, described above, will be executed as indicated below.

Item		Months after Receipt of Contract								
		1	2	3	4	5	6	7	8	9
3.2	Program Tasks	■	■	■	■	■	■	■	■	■
	Base Program	■	■	■	■	■	■	■	■	■
3.2.1	LWDSS Feature Analysis and Refinement	■	■	■						
3.2.2	Pressure Profile Code Development	■	■	■	■					
3.2.3	20-km MTP 1DVAR Retrieval Height Development		■	■	■	■				
3.2.4	150 m Profile Height Interval Development			■	■	■	■			
3.2.5	Lightning Risk Algorithm Development				■	■	■	■		
3.3	Deliverables	■	■	■	■	■	■	■	■	■
3.3.1	Kickoff Meeting	■								
3.3.2	Monthly Status Reports	■	■	■	■	■	■	■	■	■
3.3.3	Technical Review					■				
3.3.4	Final Report								■	■

4.1 RDX Team

Investigators Reed, Ware and Wilfong will develop detailed requirements and development plans for a Launch Weather Decision Support System (LWDSS) delivering:

- Accurate minute-by-minute temperature, humidity and pressure profiles at 150 m intervals to 20 km height
- Real time lightning risk identification based on MTP liquid water measurements and derived stability indices

RDX investigators will provide MTP 1DVAR data, MTP-derived stability indices and lightning risk identification data to the CAPS team for statistical evaluation.

4.2 CAPS Team

Investigators Carr, Brewster and Gasperoni will evaluate, via rigorous statistical comparison with radiosondes, the accuracy of:

- MTP variational temperature and humidity profile retrievals

[11] http://www.caps.ou.edu

- Pressure profiles derived from MTP variational retrievals

The CAPS team will also evaluate MTP-derived lightning risk identification via rigorous statistical comparison with lightning network data.

5. Related Research/ Research and Development

RDX pioneered commercial microwave profiling radiometry and continues innovative work at the forefront of this technology. RDX recently acquired RWP products including the 48 MHz RWP technology in operation at the Eastern Test Range, along with an Acoustic Wind Profiling (sodar) product line. RDX is integrating thermodynamic and wind profiling capability in ***SkyCast***^{TM} *Total Profiling Solutions*. The research and development associated with integration of atmospheric remote sensing profiling technologies is closely related to the proposed LWDSS development.

CAPS investigator (Gasperoni) is assimilating Dallas-Ft. Worth RDX MTP network data into numerical weather models for convection and precipitation forecast research as part of his doctoral thesis research.

6. Key Personnel and Bibliography of Directly Related Work

RDX and CAPS investigator information relevant to the proposed work follows.

6.1 Randolph Ware (Principal Investigator)

Founder and Chief Scientist, Radiometrics Corporation

6.1.1 Degrees

B.S., math, chemistry and physics, B.S., University of Colorado, 1966.
M.S., physics, M.S., University of Colorado, 1969.
Ph.D., experimental nuclear physics, University of Colorado, 1974.

6.1.2 Work Experience

Founder, Chief Scientist – Radiometrics Corporation, 1988 - present.

Visiting Scientist – NCAR, Mesoscale and Microscale Meteorology Division, 2007-2011; Earth Observing Laboratory, 2011- 2015; Research Applications Laboratory, 2015 - present.

Founder, Director – University NAVSTAR Consortium (UNAVCO), 1984-1998.

Principal Investigator – SuomiNet Program, UCAR, 1999-2004.

Principal Investigator – GPS/MET (now COSMIC) Satellite Radio Occultation Program, UCAR, 1991-95.

Science Fellow – CIRES, 1985-91.

US Congress – Science Fellow, Office of Technology Assessment, 1983-84.

Founder, Boulder Brewing Company, 1980.

Research Associate – CIRES, 1979-1984.

Research Associate – Joint Institute for Laboratory Astrophysics, 1974-1978.

Research Assistant – University of Colorado Nuclear Physics Laboratory Cyclotron, 1968-1974.

U.S. Marine Corps, 1962-64.

6.1.3 Publications and Patents

Dr. Ware has published 87 peer-reviewed articles in the fields of radiometry, remote sensing, and weather prediction, including several seminal studies on SLW detection. He holds 9 patents.

6.2 Kimberly Reed (Investigator)

Atmospheric Scientist, Radiometrics; Visiting Scientist, NCAR Research Applications Laboratory.

6.2.1 Degrees

B.S., Meteorology & Climatology, University of Illinois at Urbana – Champaign, 2008
M.S., Atmospheric Science, University of Illinois at Urbana – Champaign, 2011
Ph.D., Atmospheric Science, University of Illinois at Urbana – Champaign, 2017

6.2.2 Work Experience

Visiting Scientist, NCAR Research Applications Laboratory, 2016 – present
Atmospheric Scientist and Systems Engineer, Radiometrics, 2015 – present
Meteorologist and Mission Scientist, MetAtmos LTD, 2015
Graduate Research Assistant, NASA Earth and Space Science Fellow, 2009 – present

6.2.3 Publications

Reed, K. A., and S. W. Nesbitt, An Evaluation of Cold-Season Precipitation Microphysical Properties from a Radar Perspective, In Progress, 2017.

Reed, K. A., and S. W. Nesbitt, Environmental Controls on Tropical Orographic Precipitation According to the Tropical Rainfall Measuring Mission, In Progress, 2017.

Reed, K. A., and S. W. Nesbitt, February 18, 2012: A Cold- Season Precipitation Ground-Based Microphysics Case Study. In Progress, 2017.

Reed, K. A., Tropical Orographic Rainfall Regimes According to the Tropical Rainfall Measuring Mission. Master of Science Thesis, Dept. of Atmospheric Sciences, University of Illinois, Urbana, 2011.

Schroeder, A., J. Gourley, J. Hardy, J. Henderson, P. Parhi, V. Rahmani, K. Reed, R. Schumacher, B. Smith, M. Taraldsen, The Development of a Flash Flood Severity Index. Journal of Hydrology, 2016.

Serke, D. J., K. A. Reed, J. Negus, L. Blanchette, R. Ware, and P. Kennedy, A Narrow-Beam, Multi-Frequency, Scanning Radiometer and Its Application to In-Flight Icing Detection. Journal of Atmospheric Research. 2017.

Skofronick-Jackson, G., D. Hudak, W. A. Petersen, S. W. Nesbitt, V. Chandrasekar, S, Durden, K. J. Gleicher, G.-J. Huang, P. Joe, P. Kollias, K. A. Reed, M. R. Schwaller, R. Stewart, S. Tanelli, A. Tokay, J. R. Wang, M. Wolde, Global Precipitation Measurement Cold Season Precipitation Experiment (GCPEx): For Measurement Sake Let It Snow, BAMS, 2014.

6.3 Tim Wilfong (Investigator)

Atmospheric Scientist and Launch Range Specialist, Radiometrics Corporation

6.3.1 Degrees

Master of Science in Meteorology – Pennsylvania State University, 1976.
Bachelor of Science in Meteorology -- Pennsylvania State University, 1970.
Bachelor of Science in Education – West Virginia University, 1969.

6.3.2 Work Experience

Staff Meteorologist, Detect Inc., 2013-2016; Radiometrics, 2016 – present: Provide technical oversight to the installations and performance evaluations of Raptor Wind Profiler line. Develop and test new signal processing techniques.

- Provided critical inputs to the winning DeTect proposal for the NASA 50 MHz launch support wind profiler at the Eastern Test Range.
- Conducted performance evaluations during the NASA system implementation.

Chief Scientist, Next Generation National Profiler Network, Honeywell Technical Services Inc., 2007 - 2013: Provided oversight to the development, installation, and testing of the NGNPN which was planned to be up to 53 autonomous wind profiler radar sites.

- Designed meteorological data acquisition and production distribution subsystems for the NGNPN.
- Conducted the performance evaluation of the prototype Radar Unit Subsystem consisting of a wind profiler and other meteorological instrumentation.

RSA Weather Product Manager, Lockheed Martin, 2000 – 2003: Managed and provided technical direction for the $40M weather subsystem that was part of Range Standardization and Automation (RSA).

- Revitalized the weather subsystem program within the Air Force Space Command.
- Introduced Linux and the concept of using open source software to support critical launch operations to Lockheed Martin and the Space Launch Ranges.

Senior Scientist, Science and Technology Corporation, NOAA Environmental Technologies Lab, 1996 – 2000: Provided program oversight for NOAA program to improve wind profiler signal processing technology.

- Coordinated NOAA and Air Force Western Range efforts to install and test the first of a series of new network class 449 MHz wind profilers.
- Developed and executed test plans and analyzed results for the balloon-based meteorological systems used on the Space Launch Ranges.

Supervisor, Capabilities Analysis Branch, ITT Federal Services, Vandenberg AFB, 1994-1996: Supervised a branch of 21 people responsible for systems performance analysis and advanced planning for space launch range support systems.

- Produced joint Eastern and Western Range specifications for replacement sensors and processing systems based on the Global Positioning System for wind finding. Provided technical oversight to the acquisition process.
- Analyzed requirements for existing meteorological systems at both the Eastern and Western Ranges and developed long range plans for evolving more automated, cost effective support structure.

6.3.3 Publications

Wilfong, T., E. Lau, B. Weber and S. McLaughlin, Median Filter Effects on Radar Wind Profiler Spectral Noise Statistics J. Atmos. Oceanic Technol., 2014.

Wilfong, T., S. McLaughlin and E. Lau, Kennedy Space Center 50-MHz Launch Support Radar Wind Profiler, 17th Symposium on Meteorological Observation and Instrumentation, Denver, CO, 2014.

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Wilfong, T., P. Conant, K. Winters, C. Crosiar, Modernization of the space launch ranges meteorological subsystem architecture, 10th Conference on Aviation, Range, and Aerospace Meteorology, 2002.

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Wilfong, T., D. Merritt, R. Lataitis, B. Weber, D. Wuertz, and R. Strauch, Optimal Generation of Radar Wind Profiler Spectra, Journal of Atmospheric and Oceanic Technology, 1999.

Wilfong, T., D. Merritt, M. Post, D. Wuertz, B. Weber, D. Welsh, and S. King, Enhanced Profiling of Wind Temperature, Turbulence and Moisture, Fourth Int. Symp. on Tropospheric Profiling, 1998.

Wilfong, T., D. Merritt, A. Francavilla, D. Wuertz, M. Simon, B. Weber, R. Strauch, Wind Profilers: The Next

Generation, Proc COST-76 Workshop, 1997.

Wilfong, T., B. Weber, D. Wuertz, and D. Merritt, Wind Profilers: Next Generation Signal Processing, Proc. 28th Conf. on Radar Meteorology, 1997.

Wilfong, T., S. Smith, and Crosiar, Characteristics of High Resolution Wind Profiles Derived from Radar Tracked Jimspheres and the ROSE Processing Program, Journal of Atmospheric and Oceanic Technology, 1997.

Wilfong, T.., C.L. Crosiar, B. Boyd, and S. Heckman, Upper Air Data Systems to Support Space Launch Range Activities, AIAA 34th Aerospace Sciences Meeting & Exhibit, 1996.

Wilfong, T., S. Smith, and R. Creasey, High Temporal Resolution Velocity Estimates from a Wind Profiler, Journal of Spacecraft and Rockets, 1993.

6.4 Keith Brewster (Investigator)

Associate Director, University of Oklahoma Center for Analysis and Prediction of Storms (CAPS).

6.4.1 Degrees

B.S., Meteorology, University of Utah, 1981

M.S., Meteorology, University of Oklahoma, 1984

Ph.D., University of Oklahoma, 1999

6.4.2 Work Experience

Associate Director, CAPS, 2008 – present

Senior Research Scientist, CAPS, 1999—present

Adjunct Associate Professor, School of Meteorology, University of Oklahoma, 2006- present

Adjunct Assistant Professor, School of Meteorology, University of Oklahoma, 2002- 2006

Research Scientist, CAPS, University of Oklahoma, 1997-1999

Research Associate, CAPS, University of Oklahoma, 1993-1997

6.4.3 Publications

Brewster, K., and D. Stratman, An updated high-resolution hydrometeor analysis system using radar and other data. Preprints, 27th Conference on Wea. Analysis and Pred. And 23rd Conf. on Numerical. Wea. Pred., Amer. Meteor. Soc., 2015.

Brewster, K., F. Carr, K. Thomas and D. Stratman, Utilizing heterogeneous radar systems in a real-time high resolution analysis and short-term forecast system in the Dallas/Ft. Worth Testbed, 37th Conference on Radar Meteorology, Amer. Meteor. Soc., 2015.

Stratman, D., and K. Brewster, Impact of Assimilating CASA X-Band Radar Data for 24 May 2011 Tornadic Storms Using Various Microphysics Schemes at 1-km Grid Spacing. Preprints, 37th Conf. on Radar Meteor., Norman, OK, 2015.

Clark, A., S. Weiss, J. Kain, I. Jirak, M. Coniglio, C. Melick, C. Siewert, R. Sobash, P. Marsh, A. Dean, M. Xue, F. Kong, K. Thomas, Y. Wang, K. Brewster, J. Gao, X. Wang, J. Du, D. R. Novak, F. Barthold, M. Bodner, J. Levit, C. Entwistle, T. Jensen, J. Correia Jr., An Overview of the 2010 Hazardous Weather Testbed Experimental Forecast Program Spring Experiment, BAMS, 2012.

Johnson, A., X. Wang, M. Xue, F. Kong, G. Zhao, Y. Wang, K. Thomas, K. A. Brewster, and J. Gao, Multiscale characteristics and evolution of perturbations for warm season convection-allowing precipitation forecasts: Dependence on background flow and method of perturbation. Mon. Wea. Rev., 2014.

Schenkman, A., M. Xue, A. Shapiro, K. Brewster, and J. Gao, The analysis and prediction of the 8-9 May 2007 Oklahoma tornadic mesoscale convective system by assimilating WSR-88D and CASA radar data using 3DVAR.

Mon. Wea. Rev., 2011.

Brewster, K., M. Hu, M. Xue, and J. Gao, Efficient assimilation of radar data at high resolution for short range numerical weather prediction. World Weather Research Program Symposium and Nowcasting and Very Short-Range Forecasting WSN05, Toulouse, France. WMO World Weather Research Program, Geneva, Switzerland. Symposium CD, 2005.

Hu, M., M. Xue, and K. Brewster, 3DVAR and cloud analysis with WSR-88D Level-II data for the prediction of the Fort Worth tornadic thunderstorms. Part I: Cloud analysis and its impact. Mon. Wea. Rev., 2006.

Xue, M., K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, F. Carr, D. Weber, Y. Liu, and D.-H. Wang, The Advanced Regional Prediction System (ARPS) – A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part II: Model physics and applications. Meteor. Atmos. Physics, 2001.

6.1 Fred Carr (Investigator)

McCasland Foundation Professor of Meteorology, School of Meteorology, University of Oklahoma.

6.1.1 Degrees

B.S., Meteorology, Florida State University, 1969.

M.S., Meteorology, Florida State University, 1969.

Ph.D., Meteorology, Florida State University, 1969.

6.1.2 Work Experience

President, American Meteorological Society, 2017.

McCasland Foundation Presidential Professor Emeritus, 2016 – present.

National Academy of Sciences, Committee on Developing Mesoscale Observations for National Needs, 2007-2008.

Professor, School of Meteorology, University of Oklahoma, 1995-2016.

CAPS Associate Director, University of Oklahoma, 1995-2010.

Visiting Scientist, NMC, NCAR, COMET and Forecast System Lab, 1993-1994.

Assistant and Associate Professor, School of Meteorology, University of Oklahoma, 1979-1994.

Research Scientist, SUNY Albany, 1975-1979.

6.1.3 Selected Publications

Carbone, R., J. Block, S. Boselly, G. Carmichael, F. Carr, V. Chandrasekar, E. Gruntfest, R. M. Hoff, W. F. Krajewski, M. LeMone, J. Purdom, T. Schlatter, E. Takle, and J. Titlow, Observing Weather and Climate FROM THE GROUND UP: A Nationwide Network of Networks, National Academies Press, 2009.

McLaughlin, D., D. Pepyne, V. Chandrasekar, B. Philips, J. Kurose, M. Zink, K. Droegemeier, S. Cruz-Pol, F. Junyent, J. Brotzge, D. Westbrook, N. Bharadwaj, Y. Wang, E. Lyons, K. Hondl, Y. Liu, E. Knapp, M. Xue, A. Hopf, K. Kloesel, A. Defonzo, P. Kollias, K. Brewster, R. Contreras, B. Dolan, T. Djaferis, E. Insanic, S. Frasier, and F. Carr, Short-Wavelength Technology and the Potential For Distributed Networks of Small Radar Systems, BAMS, 2009:

Dabberbt, W., T. Schlatter and F. Carr, Design and development of multifunctional mesoscale observing networks in support of integrated forecasting systems, 2005.

Xue, M., K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, F. Carr, D. Weber, Y. Liu, and D.-H. Wang, The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part II: Model physics and applications, Meteor. and Atmos. Physics, 2001.

Davis, C. and F. Carr, Summary of the 1998 Workshop on Mesoscale Model Verification, 2000.

6.2 Nicholas Gasperoni (Investigator)

6.2.1 Degrees

B.S.E., Meteorology with Math and Music minors, University of Michigan at Ann Arbor, 2008.

M.S., Meteorology, University of Oklahoma, 2011.

Ph.D. candidate, Meteorology, Dissertation topic on Ensemble based Forecast sensitivity to observations including microwave profiling radiometers, 2011 – present.

6.2.2 Work Experience

Graduate Research Assistant, University of Oklahoma, 2008 – present.

Graduate Teaching Assistant, University of Oklahoma, 2015.

NASA Develop Internship, Langley Research Center, 2006.

6.2.3 Publications

Bodine, D., D. Michaud, R. Palmer, P. Heinselman, J. Brotzge, N. Gasperoni, B. Cheong, M. Xue, and J. Gao, Understanding radar refractivity: Sources of uncertainty. J. Atmos. Ocean Tech., 2011.

Gasperoni, N. A., M. Xue, R. D. Palmer, and J. Gao, Sensitivity of convective initiation prediction to near surface moisture when assimilating radar refractivity: Impact tests using OSSEs. J. Atmos. Ocean. Tech., 2013.

Gasperoni, N. and X. Wang, Adaptive localization for the ensemble-based observation impact estimate using regression confidence factors. Mon. Wea. Rev., 2015.

Ozturk, S., T. Yu, L. Ding, R. Palmer and N. Gasperoni, Application of compressive sensing to refractivity retrieval using networked weather radars. IEEE Transactions on Geoscience and Remote Sensing, 2014.

7. Relationship with Phase II or other Future R/R&D

As described throughout this proposal, Radiometrics recognizes the importance of providing atmospheric temperature, humidity and pressure profiles for use in space launch vehicle dynamic pressure analyses necessary for go/no-go launch decisions, and identifying lightning risk for space launch operations. Radiometrics recognizes this solicitation as a unique opportunity to merge expertise with CAPS investigators to develop an automated atmospheric remote sensing system to enhance launch range safety and efficiency. The RDX-CAPS team is committed to developing this system, and look forward to leveraging the proposed effort through Phase II into Phase III commercialization.

8. Company Information and Facilities

Radiometrics operates 15,000, and 5,000 square foot facilities in Boulder and Longmont, Colorado, including office, laboratory, machine shop, production, and test facilities.

9. Subcontracts and Consultants

Radiometrics has no plans to include subcontractors or consultants for this Phase I effort.

10. Potential Applications

10.1 Potential NASA Applications

The proposed atmospheric remote sensing system addresses weather-related launch complex operational challenges, providing continuous temperature, humidity and pressure soundings with radiosonde-equivalent accuracy, and liquid soundings. The system will also identify lightning risk hours in advance of traditional electric field mill methods. These features will improve launch operation safety and efficiency and will reduce the cost of access to space.

10.2 Potential Non-NASA Commercial Applications

The proposed atmospheric remote sensing system addresses weather-related challenges for non-NASA launch complex and airport operations. It provides continuous temperature, humidity and pressure soundings with radiosonde-equivalent accuracy, and liquid soundings. The system will also identify lightning risk hours in advance of traditional electric field mill methods. These features will cost-effectively improve launch and airport operation safety and efficiency.

11. Similar Proposals and Awards

Radiometrics has no similar proposals or awards for the proposed work.

12. Budget -- submitted online.