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July 22, 2019

Lorrie Alberta
UCAR
3085 Center Green Drive
Boulder, CO 80301

Dear Ms. Alberta:

This letter serves to establish our intent to collaborate and enter into a contract as Virginia Polytechnic Institute and State University (Virginia Tech) with University Corporation for Atmospheric Research (UCAR) on the enclosed research proposal, "Skill Analysis of Contemporary Operational Model Forecasts of Mixed-Precipitation Events: Guidance for the National Weather Service in the Mid-Atlantic Region." This proposal is under the leadership of Dr. Andrew Ellis in our Department of Geography. Virginia Tech fully supports this initiative. The proposed period of performance for this effort is 08/01/2019 through 06/30/20, with an estimated cost of $14,825.00.

All correspondence for this proposal should reference proposal number **PVDKGJU7.**

Virginia Tech appreciates the opportunity to participate in this important effort. Further, the referenced proposal has been prepared in accordance with applicable rules and policies regarding proposals and budgets.

Virginia Tech reserves the right to negotiate mutually agreeable terms and conditions at the time of award.

Should you wish to initiate an agreement based on the enclosed proposal, please convey acceptance of the submitted proposal and request agreement initiation in the form of an email sent directly to ospcontracts@vt.edu. Please reference the Proposal Number noted above.

The University appreciates the opportunity to submit this proposal. If fiscal or budgetary questions arise, please feel free to contact Joanna Sabal, Senior Pre-Award Associate, at 540-231-6423 or joannas@vt.edu. Technical questions should be directed to the principal investigator.

Sincerely,

Lauren P. Maguder for

Trudy M. Riley
Associate Vice President for Research and Innovation, Sponsored Programs

Partners Project Title Page
Proposal for a Partners Project

Title: Skill Analysis of Contemporary Operational Model Forecasts of Mixed-Precipitation Events: Guidance for the National Weather Service in the Mid-Atlantic Region

Date: July 15, 2019

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Regional Director
Name: Jason Tuell

SUMMARY OF BUDGET REQUEST:
COMET FUNDS: Year 1 (August 1, 2019- June 30, 2020) $14,825
NWS FUNDS: FY 2019 $0 FY 2020 $4,500

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Acting Regional Director
Name: Mickey J. Brown

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Skill Analysis of Contemporary Operational Model Forecasts of Mixed-Precipitation Events: Guidance for the National Weather Service in the Mid-Atlantic Region

Virginia Tech / National Weather Service Forecast Office-Blacksburg, Virginia

1. Problem Statement

Icing during mixed winter precipitation events can cause significant property damage and economic loss (Changnon, 2003). An autumn 2018 event across southwestern Virginia produced ice accretion of 0.1-0.5 in (0.25-1.27 cm), falling many leafed trees and branches. The event resulted in 77% of Appalachian Power customers losing electricity in rural Floyd County within the Blue Ridge Mountains. Within the four county area, more than 22,500 customers lost power, while 59 traffic accidents occurred on state roads within a four-hour period during the event (Roanoke Times, November 15, 2018). Such impactful ice events are relatively frequent for the region (Chagnon & Karl, 2003).

Local geography is often conducive to mixed precipitation events in the eastern United States, as surface-based air masses interact with the Appalachian Mountains (Keeter et al., 1995; Rauber et al., 2001). As Hux et al. noted in 2001, while the atmospheric conditions for mixed precipitation events in the mid-Atlantic region are rather well understood, "the proper forecast of type and duration of winter precipitation is one of the most difficult challenges in operational meteorology." This remains true eighteen years later.

In addition to the challenge of forecasting overall precipitation amounts in a winter event, the impact of the event can depend greatly on the amount of each winter precipitation type (p-type) and its timing. If snow or sleet is dominant, the greatest impact is on ground travel, unless the falling snow is of high water content, in which case it can also threaten the integrity of trees and power lines. If freezing rain is the dominant precipitation type, the greatest threat is to trees and power lines, while ground travel is potentially less at risk depending on ground/road temperatures. Subtle differences in the vertical thermal profile can have immense ramifications for the predominant precipitation type. Numerical weather prediction (NWP) models have improved in many ways over the last couple of decades, including increased resolution and upgrades to data assimilation systems and microphysics schemes. However, the accuracy of the vertical thermal profile, even within the first few hours of the model forecast, remains a challenge when confronted with the synoptic- and local-scale dynamics conducive to a mixed precipitation event.

In order to generate the most useful forecasts for key decision-making stakeholders, National Weather Service (NWS) forecasters generally need to refine forecast details and determine warning versus advisory headlines about 24 hours in advance of the event, if possible (national performance goals for winter storm warning lead times is currently 20 hours). Critical for forecasters is knowledge of the specific skills and biases of commonly used models, especially in terms of forecasting thermal profiles in winter events when it appears that precipitation type will be a particular challenge. Forecasting experience within the mid-Atlantic region dictates subjective knowledge, and some objective verification statistics are available for some model output (e.g., probability of precipitation, precipitation/snow amounts, surface air and dew point temperatures). However, a regional forecast skill analysis of model vertical structure during mixed precipitation type events, utilizing observed soundings and observed precipitation type, would be of tremendous benefit to forecasters across the region, both in terms of producing an official forecast as well as communicating ranges of possibilities and potential impacts to users.

For models commonly used by NWS forecasters, the proposed study will determine skill and bias in the output forecast thermal profile and expected dominant surface precipitation type, along with products derived from model output. In alignment with the needs of local NWS forecast offices, we will focus on the 24-hour forecast interval for recent (2013-2019) mixed precipitation events in the mid-Atlantic region. The goal is better understanding and use by the region's forecasters of some commonly used models in high impact mixed-precipitation events, and thus improved forecasts and communication of the range of possibilities for these events.

2. Project Objectives

The broad objective of the proposed work is to characterize skill and bias in model forecasts of thermal profile and p-type during recent mixed-precipitation events within the mid-Atlantic region. The relatively frequent occurrence of freezing rain and ice pellets east of the Appalachian Mountains stems from cold-air damming that complicates the low-level thermal profile with a "warm nose" above surface-based sub-freezing air (Rauber et al., 2001). As such, this project will look specifically at the interregional variability in model and algorithm performance (e.g. Robbins and Cortinas, 2002) that may result due to the unique synoptic and mesoscale environments associated with cold-air damming events in the region. The work of Wandishin et al. (2005) showed that individual algorithms perform better in particular scenarios and that treating a single algorithm as universally superior or inferior is incorrect. An important conclusion from that work is that model diversity is the most important consideration in developing a sufficiently dispersive ensemble, followed by algorithm diversity and initial condition diversity. This project aims to provide clear guidance to forecasters for interpretation of many of the most common models used in the first 24 hours of the forecast when confronted with a difficult p-type forecast.

The domain for the study is the area of the mid-Atlantic/central Appalachian Mountains region that is regularly susceptible to winter p-type forecast challenges due to varying degrees of cold-air damming. The study domain represents large areas of North Carolina, Virginia, and Maryland, and includes all or portions of the County Warning Areas of the Raleigh (North Carolina), Blacksburg (Virginia), Sterling (Virginia), Wakefield (Virginia) and Greenville-Spartanburg (South Carolina) forecast offices (Figure 1). The focus is on 12- to 24-hour model forecasts of thermal profiles and the dominant p-type, both within model algorithm output and derived from model output using documented approaches regularly applied by forecasters (i.e., Bourgouin, partial thickness). The area frequented by cold air damming includes three upper-air stations (Figure 1; Sterling (IAD), Blacksburg (RNK), Greensboro (GSO)) and five surface stations with reliable observed p-type data (Figure 1; IAD, GSO, Blacksburg (BCB), Roanoke (ROA), Charlottesville (CHO)).

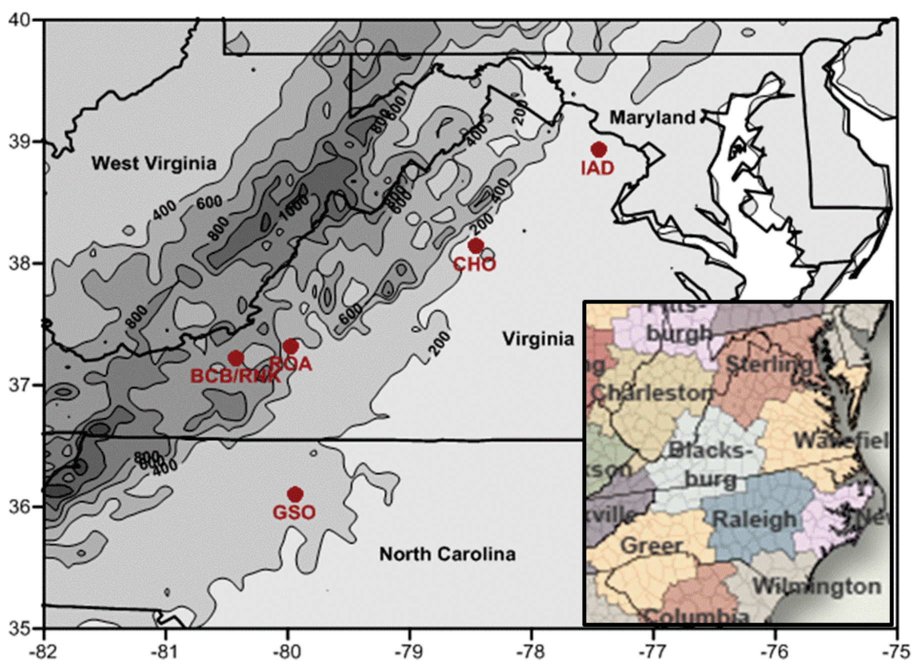

Figure 1. The study domain, including the locations of five automated surface stations for which mixed precipitation events are identifiable, three of which also serve as upper-air stations (Table 1). Elevation contours (200 m interval) illustrate the position of the stations to the east of the Appalachian Mountains. The inset map shows the County Warning Areas that overlap the study area.

Specifically, the distinct objectives of the proposed work are:

- Establish a mixed precipitation database for the region dating to the 2013-14 cool season, including characterization of each precipitation event and classification of each event by synoptic pattern.
- Establish a database of forecast model output for each mixed precipitation event, using the BUFKIT forecast profile analysis toolkit (Mahoney and Niziol, 1996), to analyze model forecasts of vertical profiles in binary universal form for the representation of meteorological data (BUFR) format. Models of focus will be the North American Mesoscale Forecast System (NAM; 12 km), the higher resolution (3 & 4 km) NAM (NAMnest), Rapid Refresh (RAP), and the High Resolution Rapid Refresh (HRRR).
- Determine forecast accuracy/bias in thermodynamic profiles from the above NWS models during precipitation events involving freezing rain/ice pellets using full model resolution and observed sounding data from three upper-air stations (IAD, RNK, GSO; Table 1, Figure 1).
    - Generate error and bias statistical scores for air temperature at key levels (surface, 900 mb, 850 mb, 800 mb) and for warm nose strength (T_{max} - $T_{surface}$).
    - Assemble detailed case studies (synoptic background, sounding analyses) of representative events.
- Determine accuracy/bias in model forecasts of dominant p-type using observed data from automated weather stations in comparison to forecast p-type from direct model output and from derivations using forecast thermal profiles and commonly applied techniques.
    - Generate simple comparative statistics (frequency bias, false alarm ratio, detection probability) for the suite of models.
    - Augment the case studies developed from the thermal profile analysis with p-type forecast accuracy data and information, including SREF output where available.
- Develop faculty and undergraduate student expertise with the BUFKIT forecast profile analysis toolkit (training.weather.gov/wdtd/tools/BUFKIT/index.php) and p-type forecasting methods.
    - Provide software training and operational forecasting instruction to students majoring in meteorology at Virginia Tech.
- Develop recommendations for the region's forecasters, based on improved knowledge of model biases in these mixed precipitation situations, for how to express confidence and ranges of possible outcomes and potential impacts.

The proposed research will directly contribute to winter weather forecasting skill and communication within the Blacksburg NWSFO and surrounding offices (Sterling, Wakefield, Raleigh, Greenville-Spartanburg) by addressing three major problems not sufficiently addressed by prior research. First, we will consider model biases in the forecast thermodynamic structure for cold-air damming events. Second, we will consider algorithm performance during cold air damming events. Lastly, this project will look specifically at the interregional variability in model and algorithm performance (e.g., Robbins & Cortinas, 2002) that may result due to the unique synoptic and mesoscale environments associated with cold air damming events in the mid-Atlantic region. Rather than creating an operational tool or application, the deliverable will be guidance for forecasters as to how individual model biases might influence model blends of first-guess fields (e.g., warm nose strength, near-surface cold layer) that influence p-type output (e.g., Wandishin et al., 2005). The objective is to improve forecaster use of these models and their conveyance of confidence, uncertainty, and expected potential outcomes and impacts. The results of the research may also inform future efforts to improve model performance, as well as the techniques or biases applied within the National Blend of Models (Tew et al., 2016) output used by local forecasters.

3. Project Activities & Methods

Activity 1: Mixed Precipitation Event Database Development (VT (lead), NWS)

It is necessary to develop three data sets of observed data for the project: mixed precipitation events for study (beginning/end dates/times, location(s)), p-type details at the five surface stations (evolution of types through each event), the vertical atmospheric profile at the three upper-air stations during each event. The mixed precipitation events database for the study region will span the six cool seasons extending from October 1, 2013 through April 30, 2019. This represents a period of enough length to yield an adequate number of events for robust study while also generally reflecting the current state of forecast models used by NWS. In developing the proposed project, we downloaded Meteorological Aerodrome Reports (METAR) from the Iowa State University Iowa Environmental Mesonet website (mesonet.agron.iastate.edu/request/download.phtml). Through cursory analysis of these data, we identified candidate mixed precipitation events during the period October 1, 2013 through April 30, 2019. This initial analysis simply utilizes the "current weather" variable within the METAR records for five locations across the region (Table 1; Figure 1).

Table 1. Stations used to identify candidate mixed precipitation events, including the three-letter code for the five surface stations and the station type (automated weather observing/surface observation systems (AWOS/ASOS)), three-letter code for the three upper-air stations, and the preliminary number of warm nose precipitation events during the period October 1, 2013 through April 30, 2019.

Name	Surface ID	Station Type	Upper-Air ID	n-Events
Blacksburg, VA	BCB	AWOS III	RNK	20
Charlottesville, VA	CHO	ASOS	-----	15
Greensboro, NC	GSO	ASOS	GSO	18
Roanoke, VA	ROA	ASOS	-----	16
Washington (Dulles), DC	IAD	ASOS	IAD	18

Nine precipitation codes (Table 2), alone or in combination, define this initial extraction of mixed precipitation events. Stratification of the data led to four event types: snow (solely SN for the duration), rain/snow (observations of SN and RA, or SNRA/RASN, but with no observations of UP, PL, FZRA, or FZDZ), warm nose (observations of UP, PL, FZRA), and shallow moisture (solely FZDZ for the duration). Of these four event types, the warm nose event will be the focus of the proposed work, since snow, rain/snow, and shallow moisture events (FZDZ generated from low-level moisture below the dendritic growth zone) do not represent mixed frozen precipitation events. Warm nose events typical of the region yield ice pellets and/or freezing rain, which may report as unknown precipitation, particularly at an AWOS station. In this initial analysis, we used Storm Events data from the National Centers for Environmental Information (NCEI) to verify the candidate events, but those data were treated as complimentary to the METAR data rather than as a primary source for identifying mixed precipitation events.

Table 2. Weather codes for identifying mixed precipitation events.

Weather	Code
Snow	SN
Snow Pellets	GS
Unknown Precipitation	**UP**
Ice Pellets	**PL**
Freezing Rain	**FZRA**
Freezing Drizzle	FZDZ
Rain	RA

Manual extraction of prolonged mixed precipitation events (≥ ~6 hours) within the six full seasons of METAR data yields a reasonably robust population of candidate events. The number of warm nose events at the five locations ranges from 15 to 20 (2.5 to 3 per year) (Table 1). The proposed research involves greater scrutiny of the METAR data and event verification through Storm Events data to overcome reporting issues, such as the prevalence of reporting UP (unknown precipitation) by the AWOS-III station at BCB. These UP reports may lead to misinterpretation of snow or rain/snow events as mixed precipitation, warm nose events.

While some of these substantial events are unique to each location, most are coincident across multiple locations. A few events are evident at all five locations. Based on METAR data, the most recent warm nose event for all five locations occurred on 20-21 February 2019, and the soundings at KRNK, KGSO, and KIAD depict a clear warm nose within the thermal profile (Figure 2).

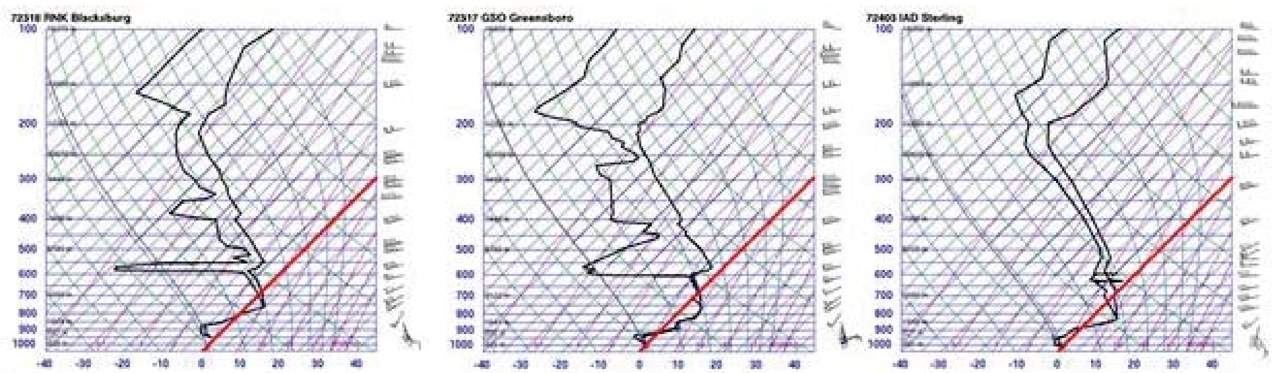

Figure 2. Soundings at KRNK (12Z, Feb 20; left), KGSO (12Z, Feb 20; center), and KIAD (00Z, Feb 21; right) during the warm nose mixed precipitation event of February 20-21, 2019. The 0°C isotherm is in red.

Project participants from Virginia Tech (VT) and the Blacksburg National Weather Service Forecast Office (WFO RNK) will collaboratively establish the warm nose events database and the evolution of p-type through each event. VT investigators will process the raw METAR data to identify all observations of PL, FZRA, and UP at the five surface stations and translate these to "events" characterized by duration and spatial coverage (i.e., fraction of the five surface stations). Descriptive data from the NCEI Storm Events database will complement the station observations, while forecaster observations at the WFO RNK will further complement the BCB observations, helping to mitigate any p-type ambiguities that the AWOS-III station presents. Further distillation of the warm nose events at BCB, GSO, and IAD will identify those coincident with the radiosonde observations (+/- 3 hours) at those sites for direct comparison of model and observed soundings. VT investigators/students will obtain sounding data through the duration of each event from the University of Wyoming (weather.uwyo.edu/upperair/sounding.html) for the three sounding stations within the region (GSO, IAD, RNK; Table 1, Figure 1). Together, VT and WFO RNK investigators will determine the array of significant warm nose events for study.

VT investigators and NWS personnel will jointly work to stratify events based on synoptic scale atmospheric pattern for finer analysis of model skill. We expect that all mixed p-type events will be associated with some degree of cold-air damming. Synoptic categories could include Miller-A (inland) or Miller-B (coastal) types of cyclogenesis, classic cold-air damming (overrunning), and cold frontal passage (low-level southerly flow above a cold surface). Daily synoptic maps from the Weather Prediction Center archives (www.wpc.ncep.noaa.gov/dwm/dwm.shtml) and mapped National Center for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis data (www.esrl.noaa.gov/psd/data/composites/hour/) will aid event classification. VT investigators and students will prepare the map library for collaborative review with NWS personnel for event type declaration.

VT investigators will prepare an interim project report describing the developed observational database. NWS project personnel will review and edit the report during the transition to the second project activity.

Activity 2: Model Database Development (VT (lead), NWS)

To assess model performance during the selected warm nose, mixed precipitation events, we will develop a comprehensive database of model forecasts. For each event, VT investigators and students will retrieve model forecast soundings in BUFR format from the model data archive at Iowa State University (mesonet.agron.iastate.edu/archive/). For each upper-air station location within the study region, soundings for each of the North American Mesoscale Forecast System (NAM), the higher resolution (3 & 4 km) NAM (NAMnest), Rapid Refresh (RAP), and High Resolution Rapid Refresh (HRRR) models will be downloaded and rendered using the BUFKIT software. We will supplement the data with Short Range Ensemble Forecast (SREF) archived data and p-type plumes from the Storm Prediction Center (SPC) where available. NWSFO RNK archived these data for some cases.

Table 3. Examples of potentially significant model changes during the proposed study period.

Date	Model Change
February 2014	RAP: Upgrade of data assimilation package; upgrade to latest WRF core & microphysics package; PBL scheme changed from MYJ to MYNN
August 2014	NAM: Upgrade of microphysics package, radiation scheme, convective parameterization scheme; changes to data assimilation (NDAS)
August 2016	RAP: New GSI analysis code (assimilation of hydrometeors and mesonet data); WRF update & microphysics upgrade
March 2017	NAM: NAMnest resolution change (4 km to 3 km); improved radiation scheme; QPF bias correction; data assimilation changes; reduction of terrain smoothing
July 2018	RAP/HRRR: Extended forecasts to 36h; data assimilation upgrade; WRF update; added hybrid vertical coordinate system; improved terrain representation; improved simulation of temperatures over terrain; improved microphysics for upper clouds

As part of the model database development, NWS personnel will document changes to the models during the study period that could influence skill/bias. Review of the National Center for Environmental Prediction (NCEP) documentation of changes to the models and the implementation dates (www.nco.ncep.noaa.gov/pmb/changes/) will identify modifications that could alter the accuracy of thermal profile/p-type forecasts. Chief among these may be changes in model resolution, changes in microphysics, and changes to data assimilation. Examples of noteworthy changes are in Table 3. It is difficult to conclude whether a given change alters model performance related to thermal profile/p-type. However, model changes will be a caveat of the proposed research, and NWS personnel are best equipped to identify those changes that may be relevant.

VT investigators will assemble an interim project report describing the developed model database. NWS project personnel will review and edit the report during the transition to the third project activity.

Activity 3: Thermodynamic Profile Analysis (VT (lead), NWS)

Prior to considering p-type, the observed thermodynamic profiles for the warm nose events coincident (+/- 3h) with soundings at the three upper-air stations (GSO, IAD, RNK) will be compared to model soundings (0h, -12h, -24h) for accuracy and bias. NWS project personnel will train VT student investigators to use the BUFKIT software, who will in-turn analyze the full model resolution output, which is available from BUFR format in the BUFKIT software.

VT investigators (and students) will compute mean absolute error (MAE) and bias scores (forecast/observed) at key levels (surface, 900 mb, 850 mb, 800 mb) for each of the models used by NWS forecasters. Composite observedmodeled differences for the full sounding will visually reveal accuracy and bias. We will repeat the analyses for the collection of events within each synoptic category. Upon reviewing the results of the analyses, NWS personnel will identify events for more intensive case study, and VT investigators and students will prepare detailed sounding comparisons and the associated synoptic background.

VT investigators will prepare a third interim project report describing the thermodynamic profile analysis and results. NWS project personnel will review and edit the report during the transition to the fourth project activity.

Activity 4: Dominant Precipitation Type Analysis (VT (lead), NWS)

As part of the extraction of model thermodynamic profiles using BUFKIT, VT student investigators will also extract dominant p-type forecasts (0h, -12h, -24h) during all warm nose events across the study region. In addition to the algorithm-derived p-type within each model, we will apply several techniques for assessing p-type to the model data (e.g., Bourgouin, partial thickness). To simplify the forecasting problem, most NWP systems use algorithms (Table 4) to provide end-users with a two-dimensional gridded forecast of the precipitation type. The majority of these algorithms are implicit since they use environmental profiles of temperature and humidity to predict the precipitation type, rather than explicitly modeling the hydrometeor and the physical processes affecting the hydrometeors and their interactions. Numerous implicit algorithms exist, but only a few studies have analyzed their performance. These limited studies have identified systematic biases toward one or more precipitation type (Manikin et al., 2004, Manikin, 2005). For example, the Baldwin algorithm has an intentional bias toward FZRA and PL types. Furthermore, Wandishin et al. (2005) showed that each algorithm performs better in particular scenarios and that no single algorithm is universally superior or inferior. It is also important to note that the p-type output provided in NWP BUFR output files may differ from that within gridded data. Table 4 includes information about the BUFR output.

Table 4. Algorithms for predicting precipitation type within models considered in this study.

Algorithm	Implicit/ Explicit	Reference	NWP Model	Notes
Thompson microphysics	Explicit	Benjamin et al., 2016	RAP, HRRR	Part of “mini-ensemble” used for BUFR output for RAP, HRRR
Ferrier-Aligo	Explicit	Aligo et al., 2018	NAM	Part of a “mini-ensemble” in NAM, including BUFR output
Partial Thickness	Implicit (statistical)	Keeter & Cline, 1991	Derived method & can be applied to any model	Not used as default in any operational models, but can be evaluated in BUFKIT
Ramer	Implicit (profile-based)	Ramer, 1993	NAM	Part of a “mini-ensemble” in NAM (& RAP, HRRR for BUFR output)
Baldwin (NCEP)	Implicit (profile-based)	Baldwin et al., 1994	NAM	Part of a “mini-ensemble” in the NAM (& RAP, HRRR for BUFR output)
Bourgouin	Implicit (statistical)	Bourgouin, 2000	NAM, but can be applied to any model through derived method	Part of a “mini-ensemble” in the NAM (& RAP, HRRR for BUFR output) & can be evaluated for any model in BUFKIT

We will match observed p-type data from the automated weather stations (some manually augmented) that defined each warm nose event with model-derived p-type data for comparison. We will segregate cases where model timing of precipitation was considerably in error and analyze these separately. P-type is a variable that is difficult to assess with conventional statistical analyses. VT investigators will generate a simple tabular illustration of the accuracy of the various model-derived p-type techniques at 0h, -12h, and -24h (i.e., frequency with which the derived p-type was realized through observation). To compute metrics of model forecast accuracy, false model-derived forecasts of FZRA or PL occurrence are necessary, in addition to the observed FZRA or PL occurrences. For the six cool seasons studied, VT students will analyze model data in BUFKIT for forecasts of FZRA or PL during what was either a snow or a rain/snow event at the automated stations (METAR data). These data complete the simple matrix (Table 5) constructed by Scheel et al. (2011) in their computations of a frequency bias index (FBI), false alarm ratio (FAR), and probability of detection (POD).

Table 5. Variables used to quantify the relationship between observed and model-derived p-type occurrence. Letters A through D relate to computation of the frequency bias index, false alarm rate, and probability of detection. Adapted from Scheel et al. (2011).

	Observed FZRA/PL	**No Observed FZRA/PL**
Forecast FZRA/PL	A	B
No Forecast FZRA/PL	C	D

VT investigators will compute the simple evaluation statistics FBI, FAR, and POD (Scheel et al. 2011) for each model-derived assessment of p-type. FBI is simply the ratio of model-derived to observed FZRA/PL occurrences, where a value greater (less) than one indicates a tendency for the model-derived products to over- (under-) forecast occurrences of freezing rain/sleet [Table 5: FBI = (A+B)/(A+C)]. FAR characterizes the fraction of model-derived forecasts of FZRA/PL not realized through observation [Table 5: FAR = B/(A+B)]. POD characterizes the fraction of FZRA/PL occurrences properly identified by model-derived forecasts [Table 5: POD = A/(A+C)].

We will repeat the analyses for the populations of warm nose events segregated by synoptic category. Upon reviewing the results of the analyses, NWS personnel will identify events for more intensive case study, and VT investigators and students will prepare detailed sounding comparisons and the associated synoptic background.

VT investigators will prepare a fourth interim project report describing the p-type analysis and results. NWS project personnel will review and edit the report during the transition to the fifth project activity.

Activity 5: Development of Forecaster Recommendations, Project Products (NWS (lead), VT)

NWS personnel will prepare a summary document for forecasters containing the key research findings and caveats, along with recommendations for use of model guidance starting points (often blends of several models) during challenging p-type events. VT investigators will aid in the preparation of the document and an accompanying Powerpoint presentation. NWS personnel will also develop a simulation of an archived p-type event for the Weather Event Simulator (WES) so forecasters can practice incorporating improved knowledge of model biases in warm nose events into their forecast preparation and in their articulation of uncertainty and potential outcomes/impacts in forecast discussions (AFDs) and briefings. VT investigators will prepare a final project report for delivery to the COMET program.

4. Timetable of Activities

The proposed project will be managed by investigators Andrew Ellis and Stephanie Zick, meteorology faculty within the Department of Geography at Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg, Virginia, and by Stephen Keighton, Science Operations Officer within the Blacksburg, Virginia National Weather Service Forecast Office. This 11-month project would begin on August 1, 2019 and end on June 30, 2020 on the following timeline:

Project Activity	Summer 2019	Fall 2019	Spring 2020	Summer 2020
1: Events database development	METAR, RAOBS, Storm Events	---	---	---
2: Model database development	---	thermal profile, p-type derivation	---	---
3: Thermal profile analysis	---	stats, case studies	---	---
4: Dominant p-type analysis	---	---	stats, case studies	---
5: Forecaster recommendations	---	---	reference & training material	reference & training material
Reporting	1: Events database	2: Model database 3: Thermal profile	4: Dominant p-type	5: Final
Salaries				
Graduate Asst	1 month	---	---	---
Undergraduate Assts	---	208 hours	208 hours	---
Conference Travel				
Senior Investigators	---	---	AMS (VT)	NWA (Keighton)

5. Expected Benefits

While numerical weather prediction models have improved in many ways over the last couple of decades, the forecast accuracy of the vertical thermal profile remains a challenge when confronted with the synoptic- and local-scale dynamics conducive to a mixed precipitation event. This is the case within the mid-Atlantic region, where cold-air damming often yields a complexity of thermal profile across the area. For the various models commonly used in the forecast process, the proposed study will characterize skill and bias in the output forecast thermal profile and expected dominant surface precipitation type, along with p-type products derived from model output. This information will benefit NWS forecasters across the mid-Atlantic region in their mission to generate the most useful forecasts for key decision-making stakeholders. As the national performance goal for lead-time on winter storm warnings is 20 hours, forecasters generally need to refine forecast details and determine warning versus advisory headlines at about 24 hours in advance of an event, while still understanding uncertainty and ranges of potential outcomes. Forecaster knowledge of the specific skills and biases of the commonly used models in this part of the forecast, along with recommendations for clearly communicating the forecast, will be of significant operational benefit. The proposed project aims to produce clear guidance for improved mixed-precipitation forecasts and communication of expected outcomes by NWS forecasters within this region.

6. Research Team and Responsibilities

Research Team (Ellis, Zick, Keighton)

Andrew Ellis, Virginia Tech

Associate Professor, Department of Geography, Virginia Polytechnic and State University, 220 Stanger Street, Blacksburg, Virginia 24061; e-mail: awellis@vt.edu

Academic Training: B.A., Geography (1991) University of Delaware; M.S., Geography (1994) University of Delaware; Ph.D., Climatology (1997) University of Delaware

Positions Held:

1997-1998	Visiting Assistant Professor, Arizona State University
1998-2004	Assistant Professor, Arizona State University
2001-2007	State Climatologist for Arizona
2004-2006	Director, Office of Climatology, Arizona State University
2004-2011	Associate Professor, Arizona State University
2010-2011	Senior Sustainability Scientist, Arizona State University
2011-pres	Associate Professor, Virginia Tech

Recent Publications (5 years):

Marston, ML, AW Ellis. 2019: Uniformity in the Temporal Distribution of Precipitation Through Seasonal and Annual Timeframes Across the Mid-Atlantic Region of the United States, 1950-2017. *Climate Research*. In Press.

Ellis AW, T Greene. 2019: Multi-scale Evidence of a Late-20th Century Change to Earlier Spring Ice-Out on Maine Lakes, USA. *Climatic Change*. 153(3), 323-339. https://doi.org/10.1007/s10584-019-02398-6

Murphy KW, AW Ellis. 2019: An Analysis of Past and Present Megadrought Impacts Upon a Modern Water Resource System. *Hydrological Sciences Journal*. 64(1), 45-65. https://doi.org/10.1080/02626667.2019/1571274

Marston ML, AW Ellis. 2018: Extreme reversals in successive winter season precipitation anomalies across the western United States, 1895-2015. *International Journal of Climatology*, 38(3), 1520-1532. https://doi.org/10.1002/joc.5263

Ellis AW, M Marston, D Nelson. 2018: An air mass-derived cool season climatology of synoptically forced Appalachian cold-air damming. *International Journal of Climatology*, 38(2), 530-542. https://doi.org/10.1002/joc.5189

Ellis AW, K Sauter. 2017: The significance of snow to surface water supply: An empirical case study from the southwestern United States. *Physical Geography*, 38(3), 211-230.

Ellis AW, P Miller. 2016: The emergence of lightning in severe thunderstorm prediction and the possible contributions from spatial science. *Geography Compass*, 10(5), 192-206.

Miller P, AW Ellis, S Keighton. 2015: The utility of total and cloud-to-ground lightning trends in diagnosing ordinary thunderstorm severity in the central Appalachians region. *Journal of Operational Meteorology*, 3, 82-98. http://dx.doi.org/10.15191/nwajom.2015.0308.

Miller P, AW Ellis, S Keighton. 2015: Spatial distribution of lightning associated with low-shear thunderstorm environments in the central Appalachians region. *Physical Geography*, 36, 127-141. http://dx.doi.org/10.1080/02723646.2015.1011257

Miller P, AW Ellis, S Keighton. 2015: A preliminary assessment of using spatiotemporal lightning patterns for a binary classification of thunderstorm mode. *Weather and Forecasting*, 30, 38-56. http://dx.doi.org/10.1175/WAF-D-14-00024.1

Stephanie Zick, Virginia Tech

Assistant Professor, Department of Geography, Virginia Polytechnic and State University, 220 Stanger Street, Blacksburg, Virginia 24061; e-mail: sezick@vt.edu

Academic Training: B.S., Meteorology (2005) Rutgers University; M.S., Meteorology (2008) Penn State University; Ph.D., Geography (2016) University of Florida

Positions Held:

2007-2008	Research Assistant, Penn State University
2008-2010	Research Associate, Naval Postgraduate School, Monterey, CA
2012-2016	Graduate Research Assistant, University of Florida
2016-pres	Assistant Professor, Virginia Tech

Recent Publications (5 years):

Zick, SE, 2019: Quantifying extreme precipitation forecasting skill in high resolution models using spatial patterns: A case study of the 2016 and 2018 Ellicott City floods, *Anthropocene*. Accepted.

Kirkland, J and SE Zick, 2019: Regional differences in the spatial patterns of North Atlantic tropical cyclone rainbands through landfall, *Southeastern Geographer*. In Press.

Matyas, CJ, SE Zick, and J Tang, 2018: Using an object-based approach to quantify the spatial structure of reflectivity regions in Hurricane Isabel (2003). Part I: Comparisons between radar observations and model simulations. *Monthly Weather Review*, 146, 1319–1340, http://dx.doi.org/10.1175/MWR-D-17-0077.1.

Zick, SE, and CJ Matyas, 2016: A shape metric methodology for studying the evolving geometries of synoptic-scale precipitation in tropical cyclones, *Annals of the American Association of Geographers*, 106, 1217-1235, http://dx.doi.org/10.1080/24694452.2016.1206460.

Chen, Y, SE Zick, and AR Benjamin, 2016: A comprehensive, cartographic approach to visualization of an evacuation map for Hurricane Ike in Galveston County, TX. *Cartography and Geographic Information Science*, http://dx.doi.org/10.1080/15230406.2015.1014426.

Zick, SE, and CJ Matyas, 2015: Tropical cyclones in the North American Regional Reanalysis: The impact of satellite-derived precipitation assimilation over-ocean, *Journal of Geophysical Research-Atmospheres*, 120, http://dx.doi.org/10.1002/2015JD023722.

Zick, SE, and CJ Matyas, 2015: Tropical cyclones in the North American Regional Reanalysis: An assessment of spatial biases in location, intensity, and structure. *Journal of Geophysical Research-Atmospheres*, 120: 1651–1669. http://dx.doi.org/10.1002/2014JD022417.

Stephen Keighton, NOAA - National Weather Service
Science and Operations Officer, National Weather Service Forecast Office, 1750 Forecast Drive, Blacksburg, Virginia 24060; email: stephen.keighton@noaa.gov

Academic Training: B.S., Meteorology (1986) Pennsylvania State University; M.S., Meteorology (1989) University of Oklahoma

Positions Held:

1989-1992	Meteorologist Intern, NWS Western Region Headquarters, Salt Lake City
1992-1995	Doppler Radar Instructor, NWS Operational Support Facility, Norman, OK
1995-1997	Science and Operations Officer, NWS Flagstaff, AZ
1997-pres	Science and Operations Officer, NWS Blacksburg, VA

Recent Publications (5 years):

Keighton, S., D.K. Miller, D. Hotz, P.D. Moore, L.B. Perry, L.G. Lee, and D.T. Martin, 2015: "Northwest Flow Aspects of Hurricane Sandy", *Weather And Forecasting*, 31, 173-195. http://dx.doi.org/10.1175/WAF-D-15-0069.1

Miller P, AW Ellis, S Keighton. 2015: The utility of total and cloud-to-ground lightning trends in diagnosing ordinary thunderstorm severity in the central Appalachians region. *Journal of Operational Meteorology*, 3, 82-98. http://dx.doi.org/10.15191/nwajom.2015.0308.

Miller P, AW Ellis, S Keighton. 2015: Spatial distribution of lightning associated with low-shear thunderstorm environments in the central Appalachians region. *Physical Geography*, 36, 127-141. http://dx.doi.org/10.1080/02723646.2015.1011257

Miller P, AW Ellis, S Keighton. 2015: A preliminary assessment of using spatiotemporal lightning patterns for a binary classification of thunderstorm mode. *Weather and Forecasting*, 30, 38-56. http://dx.doi.org/10.1175/WAF-D-14-00024.1

Research Responsibilities

Virginia Tech:

- Download and process raw METAR data to identify candidate FZRA/PL events
- Collaborate with NWS personnel to finalize FZRA/PL events for study and segregate by synoptic type
- Download BUFR model data for study events and for model forecasts of FZRA/PL that did not materialize; establish model database that includes thermal profiles, forecast dominant p-type, and derived p-type (computed from model sounding) through all events for forecast periods 0h, -12h, and -24h
- Download observed sounding and p-type data, and analyze model thermal profile forecasts and dominant p-type forecasts for accuracy/bias; compute statistics (thermal profile: MAE, bias; p-type: FBI, FAR, POD)
- Create case studies of FZRA/PL events that are typically challenging for each model
- Collaborate with NWS personnel to train undergraduate students to utilize BUFKIT software and to forecast p-type
- Collaborate with NWS personnel to develop forecaster recommendations in written form and presentation form
- Lead the writing of all interim reports and final report to COMET

- Contributions: 260 hours of contributed time from principal investigators (see budget justification); donation of computing time within Virginia Tech Department of Geography computing facilities (Wallace Hall, Blacksburg campus)

National Weather Service (NWSFO Blacksburg):

- Assist VT investigators in finalizing the FZRA/PL events for study; contribute supplemental data to include WFO Blacksburg archived p-type observations, SREF plumes, and BUFKIT SREF data
- Assist with synoptic classification of FZRA/PL events
- Provide guidance in matching hourly forecast sounding output with hourly observations, and determination of bias, when forecast-observed timing differences are significant
- Provide faculty and undergraduate student training in the use of BUFKIT and p-type forecasting techniques
- Lead the development and design of forecaster reference and training material
- Contributions: 310 hours of contributed time from NWS-Blacksburg personnel (see budget justification)

7. References

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Benjamin SG, Brown JM, Smirnova TG. 2016: Explicit precipitation-type diagnosis from a model using a mixed-phase bulk cloud-precipitation microphysics parameterization. *Weather and Forecasting* 31:609-619. https://doi.org/10.1175/WAF-D-15-0136.1

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Robins CC, Cortinas Jr JV. 2002: Local and synoptic environments associated with freezing rain in the contiguous United States. *Weather and Forecasting* 17:47-65 https://doi.org/10.1175/1520-0434(2002)017<0047:LASEAW>2.0.CO;2

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8. Budget Justification

Virginia Tech, August 1, 2019-June 30, 2020 ($14,825)

Salaries and Benefits ($7,737):

Graduate Research Assistant ($2,433)- One month of summer support (August 1-August 31, 2019) is requested for one PhD-level graduate research assistant to build the project's data structure and to develop guidance for subsequent undergraduate research assistance. Included is a fringe benefit rate of 11% of salary, which has been negotiated and approved by Virginia Tech's Federal Cognizant Agency, Office of Naval Research (ONR).

Undergraduate Research Assistants ($5,304)- Support is requested for two undergraduate research assistants to assist with data analysis, with each working 8 hours/week for 13 weeks in fall 2019 and 13 weeks in spring 2020 (416 hours total) at a hourly rate of $12.75.

26 weeks x 8 hours/week x 12.75/hour x 2 assistants = $5,304

Travel ($1,500):

Support is requested to partially defray the travel cost for one of the principal investigators to present the research at the 100th Annual Meeting of the American Meteorological Society (January 2020, Boston, Massachusetts).

Indirect Cost ($5,588):

The indirect cost is 60.5% of the Total Direct Cost (TDC). This rate has been federally negotiated and approved by Virginia Tech's Federal Cognizant Agency, ONR.

Contributed Time:

Two principal investigators (Ellis, Zick) contributing 390 hours:

Ellis (260 hours; August 2019-June 2020), Zick (130 hours; January 2020-June 2020)

National Weather Service, Fiscal Year 2020 ($4,500)

Travel ($2000):

Support is requested for travel to co-present the research at 45th Annual Meeting of the National Weather Association (September 2020).

Publication Costs ($2500):

Support is requested to partially defray the cost for publishing one project-related manuscript in an American Meteorological Society journal.

Contributed Time:

Several Blacksburg NWSFO personnel will contribute time to this project:

Keighton (270 hours, August 2019-June 2020), Silverman (40 hours; August 2019-June 2020), Others (40 hours; August 2019-June 2020)

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Eastern Region Headquarters
630 Johnson Ave. Suite 202
Bohemia, NY 11716

July 15, 2019 W/ER3x1:JSW

Dr. Lorrie Alberta
COMET Outreach Program Manager
University Corporation for Atmospheric Research
P.O. Box 3000
Boulder, CO 80307-3000

Dear Dr. Alberta:

We have reviewed the COMET Partners Project proposal between Virginia Polytechnic and State University (Virginia Tech), and the National Weather Service (NWS) Office in Blacksburg, Virginia, entitled "Skill Analysis of Contemporary Operational Model Forecasts of Mixed-Precipitation Events: Guidance for the National Weather Service in the Mid-Atlantic Region." Ice storms and mixed precipitation events present a substantial challenge for forecasters in the Mid-Atlantic region, especially across the southern Appalachian and Piedmont regions of Virginia, North Carolina, and South Carolina. These events have considerable impact on transportation, commerce, and infrastructure across the region. Thus, we strongly support the funding of this project.

Cold-air damming plays a significant role in modulating precipitation types during winter weather events across the Mid-Atlantic. It has been well documented that numerical weather prediction (NWP) models struggle with forecasting the formation, evolution, and erosion of these shallow cold air masses which are critical to accurate winter weather precipitation forecasting. This project will help provide forecasters with critical insights on the strengths, weaknesses, and biases of a number of operational NWP systems. Forecasters will also be able to apply this enhanced understanding of model behavior and performance to the developing National Blend of Models (NBM), and the associated evolving collaborative forecast processes. We are optimistic that this collaborative project will result in improved forecasts and warnings for winter precipitation across the Mid-Atlantic region.

This endeavor also builds upon the growing collaborative relationship between Virginia Tech University and the co-located NWS Blacksburg forecast office. In addition to several past collaborative projects, NWS Blacksburg has provided assistance to Virginia Tech in their efforts to develop and expand a new undergraduate meteorology program. Therefore, we enthusiastically endorse this proposal.

Sincerely,

Mickey J. Brown
Acting Director, NWS Eastern Region

Project Budget Page

	COMET Funds CY 2019-2020	NWS Contributions FY 2020
University Senior Personnel		
1. NA	NA	NA
Other University Personnel		
1. GRA, 1 month summer	$2,192	NA
2. URAs, 12.75 / hour x 416 hours	$5,304	
Fringe Benefits on University Personnel		
1. GRA, 11% of salary	$241	NA
Total Salaries + Fringe Benefits	**$7,737**	**NA**
NWS Personnel		
1. PI Keighton	NA	270 hours
2. Silverman	NA	40 hours
3. Others	NA	40 hours
Travel		
1. Conference Trips	$1,500	$2,000
Total Travel	**$1,500**	**$2,000**
Other Direct Costs		
1. Materials & Supplies	$0	NA
2. Publication Costs (put in the NWS column if a co-author will be an NWS employee)	$0	$2,500
3. Other Data	$0	$0
4. NWS Computers & Related Hardware	$0	$0
5. Other (specify)	$0	$0
Total Other Direct Costs	**$0**	**$2,500**
Indirect Costs		NA
1. Indirect Cost Rate	60.5% TDC	NA
2. Applied to which items?	Salaries/Fringe, Travel	NA
Total Indirect Costs	**$5,588**	**NA**
Total Costs (Direct + Indirect)	**$14,825**	**$4,500**

NWS Checklist for Submitting a COMET Outreach Proposal

Actions Before Proposal is Submitted to COMET	**YES**	**NO**	**DATE**
1. Did NWS office staff and university staff meet to discuss and form outline and scope of project?	X		12/14/2018 1/7/2019
2. Did NWS office consult Scientific Services Division (SSD) staff?	X		
3. Was Statement of Work and budget formulated as a team effort between university and NWS staffs?	X		4/19/2019
4. Was proposal submitted to SSD for review?	X		
5. Did SSD forward copies of proposals dealing with WSR-88D data to Radar Operations Center (ROC), Applications Branch Chief for review?	NA	NA	NA
6. Did SSD forward copies of proposals dealing with hydrometeorology to the Senior Scientist of OHD for review?	NA	NA	NA
7. Did SSD review the data request for project to ensure its scope and criticality for proposal?	X		6/7/19
8. Is all data for the project being ordered by NWS offices through the National Climatic Data Center's (NCDC) Research Customer Service Group free of charge?	NA	NA	NA
9. Does budget include publication charges and travel costs for NWS employees to present results at scientific conferences?	X		
10.Does budget separate NWS costs into fiscal year costs and university costs into calendar year costs?	X		
11.Does proposal include a separate justification for university hardware purchases which are usually not funded by the COMET Outreach Program?	NA	NA	NA
12. Have the following people signed off on the proposal cover sheet: - MIC/HIC? - SSD Chief? - Regional Director?	X		
13. Is a letter of endorsement signed by regional director attached?	X		

NWS Checklist for Submitting a COMET Outreach Proposal

Actions after Endorsement by NWS	**YES**	**NO**	**DATE**
1. University submits proposal to the COMET Program.			
2. Proposal acknowledgment letter sent by the COMET Program to submitting university with copies to SSDs and NWS office.			
3. COMET review of proposal (internal review for Partners Project proposals and formal review for Cooperative Project proposals).			
4. The COMET Program sends acceptance, rejection, or modification letters to university with copies to SSD, NWS office, and OST12.			
5. The COMET Program allocates funds for university.			
6. OST12 obligates funds for NWS offices.			
7. SSD/NWS office orders data from NCDC.			
8. NWS office or SSD calls OST12 for accounting code for expenses.			
9. NWS office sends copies of all travel vouchers and expense records to OST12.			
10. NWS office or SSD sends copies of publication page charge forms to OST12.			
11. NWS office keeps SSD informed of progress on the project and any results or benefits derived from the project.			

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
875 NORTH RANDOLPH STREET
SUITE 1425
ARLINGTON, VA 22203-1995

IN REPLY REFER TO:

Agreement Date: August 6, 2018

NEGOTIATION AGREEMENT

Institution: **VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY**
BLACKSBURG, VIRGINIA 24061

The Facility and Administrative (F&A) cost rates contained herein are for use on grants, contracts and/or other agreements issued or awarded to the Virginia Polytechnic Institute and State University by all Federal Agencies of the United States of America, in accordance with the cost principles mandated by 2 CFR Part 200. These rates shall be used for forward pricing and billing purposes for the Virginia Polytechnic Institute and State University Fiscal Years 2019 through 2021. This rate agreement supersedes all previous rate agreements/determinations for Fiscal Year 2019.

Section I: RATES - TYPE: PREDETERMINED (PRED

Facility and Administrative Cost Rates:

Type	From	To	Rate	Base	Applicable To	Location
PRED	7/1/2018	6/30/2019	61.00%	(a)	Organized Research (1)	On Campus
PRED	7/1/2019	6/30/2020	60.50%	(a)	Organized Research (1)	On Campus
PRED	7/1/2020	6/30/2021	60.00%	(a)	Organized Research (1)	On Campus
PRED	7/1/2018	6/30/2019	64.10%	(a)	Organized Research (2)	On Campus
PRED	7/1/2019	6/30/2020	63.50%	(a)	Organized Research (2)	On Campus
PRED	7/1/2020	6/30/2021	63.00%	(a)	Organized Research (2)	On Campus
PRED	7/1/2018	6/30/2021	27.50%	(a)	Organized Research (1)	Off Campus Adjacent*
PRED	7/1/2018	6/30/2019	30.60%	(a)	Organized Research (2)	Off Campus Adjacent
PRED	7/1/2019	6/30/2021	30.50%	(a)	Organized Research (2)	Off Campus Adjacent
PRED	7/1/2018	6/30/2021	26.00%	(a)	Organized Research (1)	Off Campus Remote**
PRED	7/1/2018	6/30/2019	29.10%	(a)	Organized Research (2)	Off Campus Remote
PRED	7/1/2019	6/30/2021	29.00%	(a)	Organized Research (2)	Off Campus Remote
PRED	7/1/2018	6/30/2021	53.00%	(a)	Instruction	On Campus
PRED	7/1/2018	6/30/2021	26.00%	(a)	Instruction	Off Campus
PRED	7/1/2018	6/30/2021	35.00%	(a)	Other Sponsored Activities	On Campus
PRED	7/1/2018	6/30/2021	23.30%	(a)	Other Sponsored Activities	Off Campus
PRED	7/1/2018	6/30/2021	46.00%	(a)	Agricultural Exp. Station	On Campus
PRED	7/1/2018	6/30/2021	19.50%	(a)	Agricultural Exp. Station	Off Campus

* Off Campus - Adjacent: Activities performed within the commuting area of Blacksburg, VA
** Off Campus - Remote: Activities performed outside the commuting area of Blacksburg, VA

DISTRIBUTION BASES:

(a) Modified Total Direct Costs consisting of salaries and wages, applicable fringe benefits, materials and supplies, services, travel and subawards up to the first $25,000 of each subaward (regardless of the period of performance of the subawards under the award). Equipment, capital expenditures, charges for patient care, rental costs, tuition remission, scholarships and fellowships, participant support costs and the portion of each subaward in excess of $25,000 shall be excluded from modified total direct costs. Equipment is defined as having an acquisition cost which equals or exceeds $2,000 and a useful life of more than one year.

APPLICABLE TO:

(1) Applies to all DoD contracts and subcontracts awarded before November 30, 1993, all Non-DoD instruments, and all DoD grants. (See Section II, Part E) (Capped Rate).

(2) Applies to only DoD contracts awarded on or after November 30, 1993 in accordance with and under the authority of DFARS 231.303(1). (See Section II, Part E) (Uncapped Rate).

SECTION II: GENERAL TERMS AND CONDITIONS

A. LIMITATIONS: Use of the rates set forth under Section I is subject to any statutory or administrative limitations and is applicable to a given grant, contract or other agreement only to the extent that funds are available and consistent with any and all limitations of cost clauses or provisions, if any, contained therein. Acceptance of any or all of the rates agreed to herein is predicated upon all the following conditions: (1) that no costs other than those incurred by the recipient/contractor were included in its indirect cost pool as finally accepted and that all such costs are legal obligations of the recipient/contractor and allowable under governing cost principles; (2) that the same costs that have been treated as indirect costs are not claimed as direct costs; (3) that similar types of costs, in like circumstances, have been accorded consistent accounting treatment; (4) that the information provided by the recipient/contractor, which was used as the basis for the acceptance of the rates agreed to herein and expressly relied upon by the Government in negotiating the said rates, is not subsequently found to be materially incomplete or inaccurate.

B. ACCOUNTING CHANGES: The rates contained in Section I of this agreement are based on the accounting system in effect at the time this agreement was negotiated. Changes to the method(s) of accounting for costs, which affects the amount of reimbursement resulting from the use of these rates, require the written approval of the authorized representative of the cognizant negotiating agency for the Government prior to implementation of any such changes. Such changes include but are not limited to changes in the charging of a particular type of cost from indirect to direct. Failure to obtain such approval may result in subsequent cost disallowances.

C. PREDETERMINED RATES: The predetermined rates contained in this agreement are not subject to adjustment in accordance with the provisions of 2 CFR Part 200, subject to the limitations contained in Part A of this section.

D. USE BY OTHER FEDERAL AGENCIES: The rates set forth in Section I hereof were negotiated in accordance with and under the authority set forth in 2 CFR Part 200. Accordingly, such rates shall be applied to the extent provided in such regulations to grants, contracts and other agreements to which 2 CFR Part 200 is applicable, subject to any limitations in part A of this section. Copies of this document may be provided by either party to other Federal agencies to provide such agencies with documentary notice of this agreement and its terms and conditions.

E. **APPLICATION OF INDIRECT COST RATES TO DOD CONTRACTS:** In accordance with DFARS 231.303, no limitation (unless waived by the institution) may be placed on the reimbursement of otherwise allowable indirect costs incurred by an institution of higher education under a DOD contract awarded on or after November 30, 1993, unless the same limitation is applied uniformly to all other organizations performing similar work. It has been determined by the Department of Defense that such limitation is not being uniformly applied. Accordingly, the rates cited (2) of Section I, as explained under the title, "APPLICABLE TO" do not reflect the application of the 26% limitation on administrative indirect costs imposed by 2 CFR Part 200, whereas (1) do so.

F. **DFARS WAIVER**: Signature of this agreement by the authorized representative of Virginia Polytechnic Institute and State University and the Government acknowledges and affirms the University's request to waive the prohibition contained in DFARS 231.303(1) and the Government's exercise of its discretion contained in DFARS 231.303(2) to waive the prohibition in DFARS 231.303(1) for Instruction, Other Sponsored Activities and Agricultural Experiment Station rates. The waiver request by Virginia Polytechnic Institute and State University is made to simplify the University's overall management of DOD cost reimbursements under DOD contracts.

Accepted:

FOR VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY:	FOR THE U.S. GOVERNMENT:
M. Dwight Shelton	Betty Tingle
M. DWIGHT SHELTON Jr. Vice President for Finance and Chief Financial Officer	BETTY J. TINGLE Contracting Officer
August 9, 2018	8-13-18
Date	Date

For information concerning this agreement contact:
Betty Tingle, Office of Naval Research, Phone: (703) 696-7742, Email: betty.tingle@navy.mil