Partners Project Title Page
Proposal for a Partners Project

Title: **High Resolution Numerical Modeling of Mountain Wave Wind Events in the Southern Appalachians Mountain Region**

Date: 10 March 2021

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SUMMARY OF BUDGET REQUEST:

COMET FUNDS: Year 1_$13,939_

NWS FUNDS: FY 1__$2500 ________ FY 2__ $0 ________

High Resolution Numerical Modeling of Mountain Wave Wind Events in the Southern Appalachians Mountain Region

Virginia Tech/U.S. Forest Service/NOAA National Weather Service Morristown, TN

1. Problem Statement

Mountain ranges worldwide are known for disturbances when statically stable, stratified air is kinematically forced to ascend the topographic barrier. These disturbances produce energy, which is forced away from the barrier through the generation of internal gravity waves which propagate downstream from the disturbance site. These internal gravity waves are commonly referred to as mountain waves (Durran 1990). Mountain waves can transfer momentum in statically stable environments to the surface on the lee slope, resulting in strong wind gusts in excess of 40 m s^{-1} across numerous mountain chains, including both the Rocky and Appalachian Mountains (Brinkmann 1974; Lilly 1978; Durran 1990; Cotton et al. 1995; Gaffin 2009). Mountain wave induced wind gusts of slightly lower magnitude have also been noted in areas of the U.S. with significantly lower elevation, including mountain wave induced gusts of 30 m s^{-1} immediately downwind of High Point, New Jersey (elevation 550 m) in the Kittatinny Mountains. (Decker and Robinson 2011). The non-convective winds produced by mountain waves can lead to large tree falls, power outages, and property damage (Brinkmann 1974; Cotton et al. 1995; Gaffin 2009). Terrain induced wind gusts have also been associated with fatalities and represent ~6% of all non-convective wind fatalities in the U.S. (Ashley and Black 2008). In addition to surface based hazards, mountain waves are commonly associated with severe clear air turbulence which can lead to fatal aviation disasters (Lilly 1978; Knox et al. 2008). Lee mountain waves have also been shown to be related to the formation of rotors, which have been cited as contributing to numerous aircraft accidents (Doyle and Durran 2002).

Many theoretical and computational studies over the last four decades into mountain wave generation and their translation to surface wind gusts have yielded a growing understanding of the dynamics involved with these processes. Linear and nonlinear theories have been employed to advance this understanding. The role of sharp temperature inversions on influencing gravity-wave and near-surface flow structure has been elucidated. Linear theory developed by (Klemp and Lilly 1975) found that vertical gravity waves, induced by topography can reflect off a low-level temperature inversion. Additionally, they found that the depth, height, and temperature difference across the inversion played a critical role in determining the downslope surface wind speed. In addition to temperature inversions, internal gravity waves have been suggested to reflect off of levels of the troposphere where the cross-barrier component of the flow goes to zero, these levels are commonly referred to as critical levels (Clark and Peltier 1984). Wave breaking has also been found to play an important role in some downslope wind events (Clark and Peltier 1977; Durran 1986). In the absence of a critical level, mountain waves can trap gravity wave energy within the underlying flow, effectively imposing an upper boundary condition similar to a critical level (Smith and Sun 1987; Durran 1990). Research has shown that downslope windstorms increase in magnitude and likelihood when a critical layer and/or wave breaking is present (Durran 1986, 1990; Gaffin 2009; Decker and Robinson 2011).

Nonlinear interactions are responsible, at least in part, for the generation of downslope windstorms in response to mountain wave generation (Durran 1986, 1990; Vosper 2004). An example of this nonlinearity is the existence of a critical Froude (Fr) threshold where the flow surmounting topography transitions from subcritical (Fr < 1) to supercritical (Fr > 1) flow, representing a conversion of potential to kinetic energy and increasing wind speeds downslope (Durran 1986, 1990). One of the most thorough investigations of nonlinearities highlighted the role of the strength and vertical position of the temperature inversion in the magnitude of the downslope windstorm (Vosper 2004). With weak inversions, numerical experiments show no low-tropospheric reflection of the vertically propagating gravity (mountain) waves (Vosper 2004). However, strong inversions, particularly when they are situated directly above the mountain top, were capable of producing a continuum of responses including trapped lee waves, lee waves with rotors, and hydraulic jumps (Meyers et al. 2003; Vosper 2004; Decker and Robinson 2011; Doyle et al. 2011). These hydraulic jumps represent the most severe and extreme wind events.

This project addresses the need for NWS meteorologists at NWS MRX and other nearby offices to better understand the extent and intensity of these events and to determine the synoptic/mesoscale forcings that help set the background flow and thermal structure to produce mountain wave wind events (MWWEs) in the Southern Appalachian Mountains. Historically, meteorologists have understood when these events may occur in their respective County Warning Areas (CWAs) but have been unable to provide Emergency Managers with specific details on the extent and intensity expected due to the highly localized nature of these features because they are typically poorly resolved (e.g. sub-grid scale processes) by the Global Forecast System (GFS) and North American Model (NAM). This project will thus address two primary research objectives:

1) Use a high-resolution NWP model to better understand the spatial extent and intensity of historical mountain wave wind events (MWWEs) in the Southern Appalachian Mountains.
2) Leverage a machine learning pattern recognition methodology (e.g. self-organizing maps) to determine the synoptic/mesoscale forcing mechanisms that form the background flow and thermal profiles leading to the MWWEs, with an emphasis on differentiating between minor, moderate, and extreme events.

2. Project Objectives

The National Weather Service in Morristown, TN, partners on this project are in the final stages of identifying cases since 2010 where two weather observation stations reported wind gusts in excess of 40 mph without any apparent localized convective processes. Through simulation of these case studies, we will examine the Weather Research and Forecast (WRF) models ability to simulate these low-frequency, high-impact events while also improving the understanding of the large scale forcing mechanisms that drive these local scale wind events. This project aims to use the WRF simulations to improve the understanding of the spatial extent and intensity of these events that tend to occur in remote terrain with little reliable ground observations. Secondarily, a machine learning methodology (self-organizing maps) will be implemented to resolve the synoptic to mesoscale circulations and thermodynamic profiles that drive these wind events. Linking the local scale wind event to the larger scale environment will help improve the predictability of extreme mountain wave wind events in the Southern Appalachian Mountains in order to provide forecasters better 5-7 day guidance to better prepare the public and stakeholders for high-impact mountain wave events.

While mountain wave induced wave events have been well researched and documented on the Front Range and other portions of the Rocky Mountains, the Appalachian mountains have yielded less attention from the research community. This project will address this gap in the literature, providing the first high-resolution modeling study focused on mountain wave generation in the Southern Appalachian Mountains.

This study will leverage the WRF Model to simulate MWWEs in the Southern Appalachian mountain region (Skamarock et al. 2008). The WRF Model has become one the most widely used nonhydrostatic, numerical weather prediction models in the world both for operational forecasting and research purposes (Powers et al. 2017). WRF can be configured to conduct idealized simulations such as flow over topography, making it ideal for research applications. WRF has a sophisticated data assimilation scheme, allowing for both three- and four-dimensional variational approaches, making it capable of assimilating a wide range of direct and indirect observations types (Barker et al. 2012). WRF has great flexibility and allows for high-resolution studies, as it can scale to convection permitting spatial scales (< 4km). Recent studies run WRF in idealized settings at horizontal resolutions on the order of ~50m and have been used to model mountain wave generation (Doyle et al. 2011; Powers et al. 2017).

Specifically, the objectives of this research are:

1. Identify case studies in the Southern Appalachian region where mountain wave events produced observed, localized downslope wind events [NWS].
2. Determine the ability of Advanced Research WRF (WRF-ARW) to resolve the observed wind speeds by calculating standard error between the nearest WRF grid point and the observed wind speeds [USFS, VT].
3. Use WRF-ARW to determine the spatial extent and magnitude of the wind events, which will help inform whether these events are as isolated as they appear in observations, or are more widespread but lack anemometer instrumentation to measure these events [USFS, VT, NWS]
4. Model the synoptic/mesoscale pressure and wind fields with a machine learning pattern recognition (e.g. self-organizing map) methodology to elucidate common modes of variability driving mountain wave events in the study domain [VT, USFS].
    a. Use the boundary condition data (e.g. NAM Analysis) and/or reanalysis (e.g. NARR or ERA5) for each case study to build self-organizing maps of the mesoscale/synoptic pressure fields to determine common forcing environments for mountain wave events in the study domain.
5. Use the modes of variability to produce common conceptual models for minor, moderate, and severe mountain wave wind events, to improve short- to medium-range forecasting of these events [VT, USFS, NWS].
6. Develop undergraduate student expertise in utilizing self-organizing maps for climate modeling purposes [VT].

3. *Project Activities and Methods*

Activity 1: Identify case studies in the Southern Appalachians [NWS]

First, it is necessary to build a comprehensive case study database. Therefore, meteorologists at the Morristown National Weather Service Forecast Office (WFO MRX) will build a database of probable mountain wave wind events (MWWEs). These case studies will consist of days with high winds from the NOAA Atmospheric Turbulence and Diffusion Division Camp Creek Meteorological Tower and the National Park Service Air Resource Division observation at Cove Mountain without any apparent convective forcing. We will aim to identify roughly 50 case studies from the period 2010-2020 while categorizing the events into extreme (> 90 mph), moderate (70-90 mph), and minor (< 70 mph).

Deliverable: NWS investigators will deliver case study reports to the USFS/VT researchers to initiate and guide Activities 2-6.

Activity 2: Determine the ability of Advanced Research WRF (WRF-ARW) to recreate the observed wind speeds [USFS, VT]

The Advanced Research WRF (WRF-ARW) will be employed to model a Southern Appalachian domain, with the highest topography situated roughly in the middle of the domain (Figure 1). Use the WRF-ARW numerical weather prediction system to create idealized simulations of the 72-96 hour temporal range around the mountain wave case studies. This temporal range allows the model to appropriately spin-up before mountain wave initiation and to allow for the mountain wave production to end (Skamarock et al. 2008). The proposed model specifications are to run WRF-ARW for the domain at 500 m resolution, which yields 87,992 grid points, 647 in the x-direction and 136 in the y-direction. As proof of concept, one simulation was conducted for a case study for a December 2009 mountain wave wind event (Figure 2). In the simulation, a large swath of >50 kts winds are resolved in the higher terrain of east Tennessee and southwest Virginia. The data output from WRF for this 4-day simulation totaled 481 GB. This is evidence of the computational expense of these high resolution simulations. If all case studies currently identified (e.g., 46) are to be done, it would yield approximately 22 TB of data output. During the course of the funding period, at least 21 simulations will be completed. We will rank the events by observed wind speed and sample the events accordingly. We will simulate at least the 7 strongest events, 7 weakest events, and 7 moderate events (determined by selecting the median event and +/- 3 days. The simulation presented in Figure 2 invoked roughly 65,000 core hours of processing.

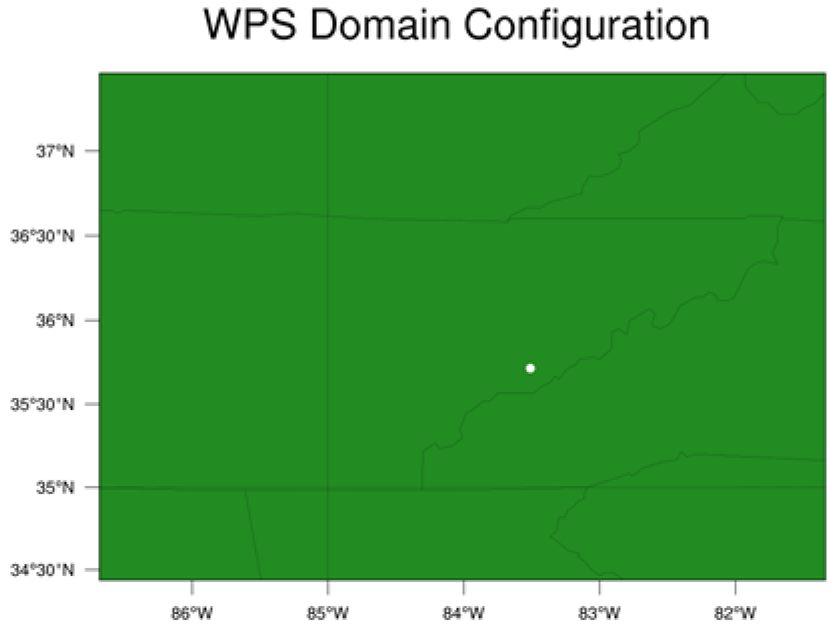

Figure 1. Suggested domain for the Southern Appalachian mountain wave simulations. White dot in the city of Gatlinburg, TN for reference.

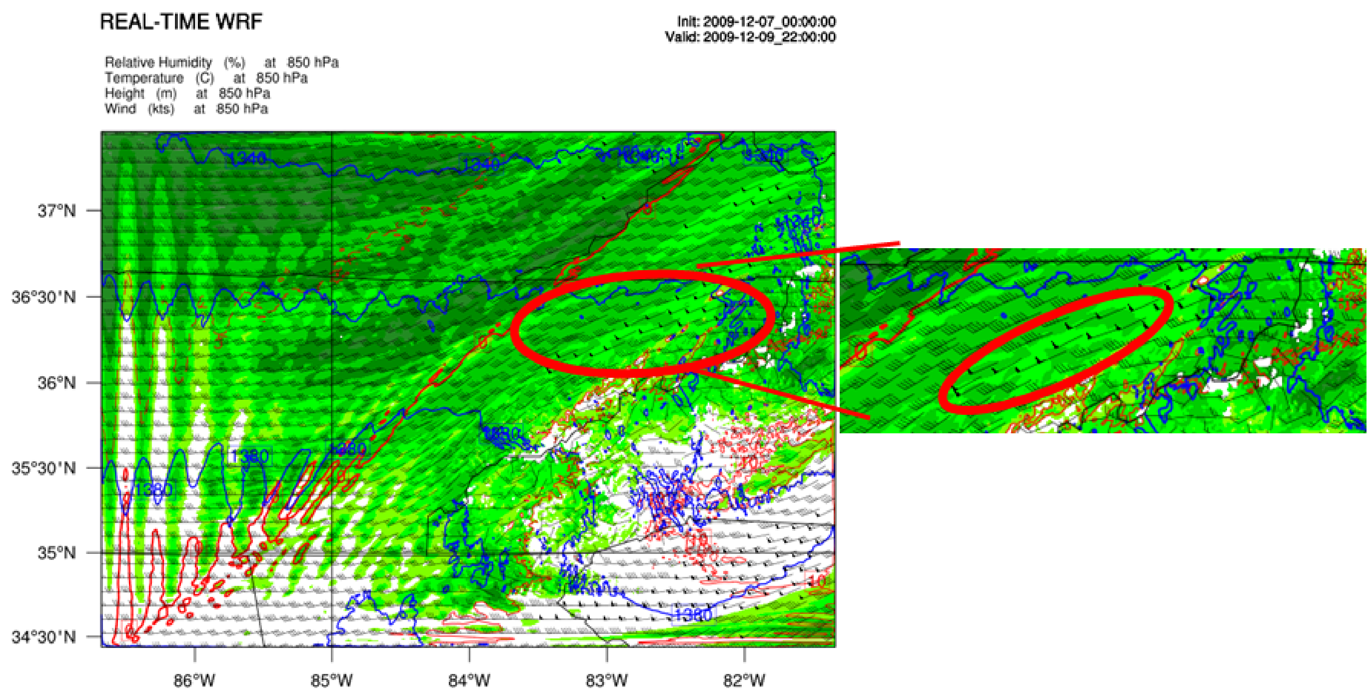

Figure 2. WRF simulation for Dec 09, 2009 at 22Z using 500m grid spacing for the study domain. Inset map highlighting a large swath of >50 kts winds that would have been unresolved at coarser resolution simulations.

Due to the modeling complexity being proposed, PIs Ramseyer and Williams will conduct modeling simulations on the Tinkercliffs high performance computing cluster at Virginia Tech's Advanced Research Computing (ARC) supercomputer. Tinkercliffs comprises 308 Cray base compute nodes (with AMD EPYC 7702 chips), with each node having 128 cores, totaling 39,424 total cores. The cluster also has 78,848 GB of total memory allocated to the base compute nodes. Tinkercliffs also has high memory nodes available on the cluster which brings the total number of cores to nearly 42,000. Initially, PI Ramseyer has been allocated 600,000 core hours/month from the ARC for this project. PI Ramseyer has also entered into a memorandum of understanding with the ARC for the purchase and install of a dedicated node to PI Ramseyer's research objectives (i.e. this node will not be shared with other university faculty) with 128 cores in addition to the 600,000 core hours/month already allocated.

As simulations are conducted, error metrics (e.g. mean absolute error) will be calculated to determine the ability for WRF-ARW to recreate the observed wind gusts in the high terrain, by quantifying the error between the nearest WRF grid point and the observed winds for each event. These simulations will begin with the case studies with the most extreme wind gusts, if significant underpredictions of winds are observed, alternative model specifications and parameterizations will be employed.

Deliverable: Manuscript authored by all members of the research team presenting the error metrics of the most extreme case studies (> 90 mph) to illustrate WRF-ARWs ability to recreate the highly localized wind gusts.

Activity 3: Determine the spatial extent and magnitude of the simulated wind events, which will help inform whether these events are as isolated as they appear in observations, or are more widespread but lack anemometer instrumentation to measure these events [USFS, VT, NWS]

At the conclusion of the idealized simulations of the case studies (~21), the cases will be analyzed to determine the spatial extent and the magnitude of the MWWEs. This will involve determining the value added with the WRF simulations compared to the existing observation network. This will help to better understand if these events are as isolated as they appear in observations, or if the wind events are larger in spatial extent but current observations network underreport such events. Additionally, a differentiation of low, moderate, and high impact MWWEs will be conducted, to determine if spatial extent has significant correlation to peak wind gusts in the domain.

Deliverable: Manuscript #2 authored by all members of the research team to be submitted to a high-impact meteorology journal presenting the findings of Activity 3. Additionally, activities 2 and/or 3 will be presented at the 2022 American Meteorological Society Annual Meeting by a member of the research team.

Activity 4: Model the synoptic/mesoscale pressure and wind fields with a self-organizing map methodology to elucidate common modes of variability driving mountain wave events in the study domain [VT].

This activity will be conducted simultaneously with activities 2 and 3. This is made possible by the fact that once the case studies are identified, activity 4 can commence. This activity will involve creating self-organizing maps (SOMs), a form of artificial neural network, to model and determine the leading modes of variability associated with MWWEs. The input training data will be either the NAM analysis data used to initialize the WRF model, or, ERA5 reanalysis data from ECMWF for the case study events. ERA5 data are available hourly, on 0.25x0.25 spatial grids, and have 137 vertical levels. This would allow for a thorough analysis of the conditions leading up to, at the height of, and the termination of the wind event.

Initially, the predictor variable used to produce the SOMs will be surface pressure and 925-hPa wind fields. These were selected based on preliminary research by NWS Morristown investigators Buckles and Anderson. Ideally, the SOM would not involve multiple predictor variables since the primary objective is to create something usable for operational meteorology. Once the SOMs are trained using pressure data, the SOM will detect common modes of variability or (groups) of pressure gradients on the synoptic-/meso-scale. These modes of variability would represent that common "setups" that produce MWWEs.

To carry out activity 4, the same computational resources at ARC will be leveraged including the Tinker Cliffs computing cluster. The SOMs will be built using a combination of PyPi and PyTorch modules using Python 3.6 computing language. These modules are currently available on the Tinker Cliffs cluster. It is expected that the VT undergraduate students funded through this project will help conduct these SOM modeling exercises. They will also be asked to create SOMs analyzing other predictor variables other than surface pressure (i.e. stability metrics, etc).

Deliverable: Manuscript #3 authored by all members of the research team (and potentially undergraduates) to be submitted to a high-impact meteorology journal presenting the findings of Activity 4 and 5. Additionally, undergraduates will be invited to present their research at the NWS Southern/Central Appalachian Weather and Climate Workshop in the Spring of 2022.

Activity 5: Use the modes of variability to produce common "atmospheric set-ups" for minor, moderate, and severe mountain wave wind events, to improve short- to medium-range forecasting of these events [VT, USFS, NWS].

This activity will also act as the culmination of the prior activities (1-4). The WRF runs (Activities 2 and 3) will provide context on how widespread these observed events are and if they are adequately sampled and represented by the two observations available at high elevation (from Activity 1). It is hypothesized that these events may cover a larger spatial domain, and could be higher intensity, but due to the lack of observations in the remote terrain, are underreported. The WRF runs will thus provide a more holistic representation of the MWWEs identified in Activity 1.

A natural follow-up to the initial SOM research in Activity 4 will be to better understand the spatial extent and magnitude of the wind events for each of the modes of variability produced by the SOM. This will help forecasters better understand the more discrete characteristics and setups of minor, moderate, and severe MWWEs. This process can then be operationalized by the forecasters qualitatively analyzing operational model output to determine if the large scale forcing is conducive to minor, moderate, or severe MWWEs.

The findings from the WRF and SOM activities will culminate with a training simulation, produced by both VT and NWS MRX, of the Gatlinburg, TN event. This training simulation will also be embedded in a more comprehensive training module which will help forecasters:

1) Understand the synoptic/mesoscale forcings and patterns that can lead to minor, moderate, and extreme events to help forecasters find these patterns in the GFS and NAM operational models several days in advance.
2) Understand the extent and intensity of these events as elucidated from the WRF model runs, with detailed analysis of the vertical and spatial extent of the events. This will help extend the understanding of the impact of these events outside of the sparse observations available in the high terrain.

NWS MRX (Investigator Motz) will lead the design of the training simulation and module while VT will assist in producing visualizations from the research. The training module and simulation will be instrumental in translating the research to a useful operation application, which is ultimately the primary objective of COMET Partner Projects.

Future research, after the conclusion of the research presented in this proposal, would work to make the operalization more formal where operational data could be fed into the SOM and produce a probability of a MWWE given the synoptic situation.

Deliverable: Manuscript authored by all members of the research team (and potentially undergraduates) to be submitted to a high-impact meteorology journal presenting the findings of Activity 4 and 5. Additionally, undergraduates will be invited to present their research at the NWS Southern/Central Appalachian Weather and Climate Workshop in the Spring of 2022.

Activity 6: Develop undergraduate student expertise in utilizing self-organizing maps for climate modeling purposes [VT].

An important portion of this proposed research is the involvement of undergraduate students, in particular, the funding of two student researchers who will assist primarily in objectives 4 and 5. If one or both of the student researchers were interested in learning more about the WRF modeling exercises, the USFS and VT researchers would be willing to teach them as well. The ideal student researchers will be interested in graduate school in the Atmospheric Sciences. The exposure to big data, machine learning, and high-performance computing will provide unique opportunities to engage in high-impact research and greatly improve their marketability and preparedness for graduate school assistantships.

Deliverable: Student researchers will be exposed to high performance computing and machine learning for meteorological modeling and will be invited to present their research at the NWS Southern/Central Appalachian Weather and Climate Workshop in the Spring of 2022.

4. Timetable of Activities

The proposed project will be managed by investigator Craig Ramseyer, meteorology faculty at the Department of Geography at Virginia Polytechnic Institute and State University (VT) in Blacksburg, Virginia; investigator Marcus Williams, research meteorologist at the USDA United States Forest Service (USFS) in Athens, Georgia; David Hotz, Science Operations Officer within the Morristown, Tennessee National Weather Service (NWS) Forecast Office; and Matt Anderson, meteorologist within the Huntsville, Alabama NWS Forecast Office. This 12-month project would begin August 1, 2021 and end on July 31, 2022 on the following schedule:

Timetable Of Activities				
Project Activity	Summer 2021	Fall 2021	Spring 2022	Summer 2022
1 – Finalize Case Studies	NWS	—	—	—
2 – WRF Runs/Error Determination	USFS/VT	USFS/VT	USFS/VT	—
3 – WRF Runs/Magnitude and Spatial Extent of MWWEs	—	USFS/VT	USFS/VT	USFS/VT
4 – SOM Modeling and Tuning	—	VT	VT	—
5 – SOM Forecasting Utilization and MWWE severity	—	—	VT	VT/USFS/NWS
6 – Undergraduate Research and Involvement	—	VT	VT	—
Salaries				
—	—	UG Salary (224 hours)	UG Salary (224 hours)	–
Conference Travel				
—	—	—	AMS and NWS Workshop	–

__Research Responsibilities__

Virginia Tech:

- Complete > 20 WRF-ARW simulations of mountain wave wind events (MWWEs) on the Tinker Cliffs HPC cluster at Virginia Tech [with USFS].
- Analyze WRF output to determine the ability for the simulations to capture the magnitude and spatial extent of the observed wind gusts [with USFS].
- Analyze the WRF output to discretize the dynamical forcing of minor, moderate, and severe events [with USFS].
- Create and tune SOMs to determine common synoptic "setups" of minor, moderate, severe using well-resolved, long-range NWP, atmospheric fields (e.g. surface pressure, temperature profile).
- Co-author guidance on how the WRF simulations and SOMs can aid forecasters in predicting MWWEs in the Southern Appalachians.
- Lead and/or co-lead (with USFS) writing of all peer-review manuscripts and final report to COMET/UCAR.
- Provide research expertise, support, and mentorship to the undergraduate research assistants.
- Present preliminary findings at AMS Annual Meeting and NWS Workshop.

- Contributions: >250 hours of contributed time by principal investigator Ramseyer and donation of > 1 million core hours on Tinker Cliffs cluster.

National Weather Service (NOAA/NWS Morristown)

- **Lead production of training simulations and training modules related to Activities 2-5.**
- Provide case studies to principal investigators, comprising minor, moderate, and severe events.
- Assist with SOM predictor variable selection based on local expertise.
- Co-author guidance on how the WRF simulations and SOMs can aid forecasters in predicting MWWEs in the Southern Appalachians.
- Co-author peer-review manuscripts developed in the study.
- Lend expertise and student mentorship to the undergraduate research assistants.
- Present findings at the NWA and AMS annual conferences
- Present findings at the Southern Appalachian Weather Workshop 2022
- Contribution by Mountain Wave High Wind Research Anderson/Buckles 2019

Expected Benefits

Mountain wave wind events (MWWEs) are highly localized meteorological phenomena that often produce wind gusts at the sub-grid scale of most operational numerical weather prediction (NWP) models. Thus, these events are often difficult to forecast, particularly at the >1-2 day time scale. The lack of representation of these events in medium- and long-range NWP models (e.g., GFS andEuropean IFS) provides little to no lead time for forecasters and stakeholders. Yet, these events can produce wind gusts exceeding hurricane force gusts in relatively quiescent synoptic conditions. Thus, MWWEs, despite being able to produce damage to structures and vegetation, are hard to predict.

This study will aid NWS forecasters in the Eastern and Southern Regions in better understanding the dynamics that produce MWWEs in the Southern Appalachians by producing novel high-resolution WRF-ARW simulations for a suite of case studies ranging from minor to severe events. This will allow researchers and forecasters to better understand the spatial extent and magnitude of MWWEs and no longer be restricted to sparse observations of winds in the study region.

Additionally, researchers will produce self-organizing map models of the common synoptic/mesoscale atmospheric drivers and setups of these MWWEs. These synoptic conditions are better resolved by long-range NWP models, thus, an expected benefit of this study is elucidating the synoptic “setups” for minor, moderate, and severe MWWEs that would be better represented in long-range NWP. Ideally, this would increase the lead time forecasters can provide into impending MWWEs and help descritize between a minor versus severe event. This added lead time and detail into the magnitude of the wind event would provide value to both the NWS forecasters and stakeholders.

Lastly, this study is intended to benefit the undergraduate research assistants. No opportunity currently exists in our Meteorology curriculum and/or research portfolio to expose undergraduate students to high performance computing, machine learning, and NWP modeling. Students will be exposed to all three of these research realms and it will provide the students with significant career development and graduate school funding opportunities. Another benefit of this proposed project to the students would be funding to travel to the AMS annual meeting in Houston in January 2022 and/or a NWS Southern Appalachian Weather and Climate Workshop that is currently in development for delivery in the spring of 2022. This will provide the student researchers the opportunity to present their research in a professional setting while also gaining invaluable networking and career development opportunities.

5. Research Team and Responsibilities

Research Team (Ramseyer, Williams, Hotz, Anderson, Buckles, Gant)

Craig Ramseyer, Virginia Tech

Assistant Professor, Department of Geography, Virginia Polytechnic and State University, 220 Stanger Street, Blacksburg, Virginia 24061; ramseyer@vt.edu

Education

2016	Ph.D. in Geography – University of Georgia, Athens, GA.
2011	M.S. in Geography – University of Georgia, Athens, GA.
2009	B.S. in Geography with Honors and Distinction – James Madison University, Harrisonburg, VA.

Academic Appointments

2019–present	Assistant Professor (tenure-track), Virginia Polytechnic Institute and State University, Department of Geography
2016–2019	Assistant Professor (tenure-track), Salisbury University, Department of Geography and Geosciences

Recent Publications (since 2016)

2020	Miller, P.W. and **C.A. Ramseyer**: Did the Climate Forecast System anticipate the 2015 Caribbean drought? *Journal of Hydrometeorology*, **21**, 1245–1258, doi: 10.1175/JHM-D-19-0284.1
2019	**Ramseyer C.A.**, T.L. Mote, and P.W. Miller: Future Precipitation Variability during the Early Rainfall Season in the El Yunque National Forest. *Science of the Total Environment*, **661**, 326–336, doi:10.1016/j.scitotenv.2019.01.167.
2019	Miller, P.W., T.L. Mote, **C.A. Ramseyer**: An empirical study of the relationship between seasonal precipitation and thermodynamic environment in Puerto Rico. *Wea. Forecasting*, **34**, 277–288, doi:10.1175/WAF-D-18-0127.1.
2018	**Ramseyer, C.A.** and T.L. Mote: Empirical Downscaling of Historical Rainfall in Northeast Puerto Rico using Self-Organizing Maps. *International Journal of Climatology*, **38**, e224–e236, doi:10.1002/joc.5364.
2018	Miller, P.W., T. L. Mote, **C. A. Ramseyer**, A. E. Van Beusekom, M. A. Scholl, and G. González: A 42-yr Inference of Cloud Base Height Trends in the Luquillo Mountains of Northeastern Puerto Rico**.** *Climate Research*, **76**, 87–94, doi:10.3354/cr01529.

2017	Mote, T.L., **C.A. Ramseyer**, and P. W. Miller: The Saharan Air Layer as an Early Rainfall Season Suppressant in the Eastern Caribbean: The 2015 Puerto Rico Drought. *Journal of Geophysical Research – Atmospheres*, **122**, 10966–10982, doi: 10.1002/2017JD026911.
2016	Mattingly, K.S., **C.A. Ramseyer**, J.J. Rosen, T.L. Mote, and R. Muthyala: Increasing water vapor transport to the Greenland Ice Sheet revealed using Self-Organizing Maps. *Geophysical. Research Letters,* **43**, 9250–9258 doi:10.1002/2016GL070424.
2016	**Ramseyer, C.A.** and T.L. Mote: Atmospheric Controls on Puerto Rico precipitation using Artificial Neural Networks. *Climate Dynamics*, **47**, 2515–2526, doi:10.1007/s00382-016-2980-3.

Grant Support (since 2020)

2020 – 2023	Mote, T., P.W. Miller, C.A. Ramseyer (Co-PI), and G. Gonzalez. *Understanding the Mechanisms Leading to Early Warning of Meteorological and Hydrological Drought in the U.S. Caribbean*. NOAA Climate Program Office. (Total: $507,198; Virginia Tech: $154,367)

Professional Service Activities (since 2020)

2020–present	Executive Committee (Secretary), Southeastern Division of the American Association of Geographers
2020–present	Member, NOAA Drought Task Force IV
2020–present	Journal Reviewer, *Climate Research*, *Journal of Geophysical Research-Atmospheres*
2020–present	Member, CNRE Student Policy and Affairs Committee
2020–present	Member, VT Department of Geography Degree Committee
2020	External Consultant, JMU Geographic Science Program Review Committee
2020	Invited panelist, ‘Factfulness and Climate Change’, JMU Honors College
2020	Invited seminar lecturer, Old Dominion University Center for Coastal Physical Oceanography and Institute for Coastal Adaptation and Resilience

Marcus Williams, USDA U.S. Forest Service

Research Meteorologist, USDA United States Forest Service, 320 Green Street, Athens, GA 30602

Education

2016	Ph.D. in Geography – University of Georgia, Athens, GA.
2010	M.S. in Meteorology – Florida State University, Tallahassee, FL.
2006	B.S. in Meteorology – Florida State University, Tallahassee, FL.

Appointments

Research Meteorologist, United States Forest Service, 2016 - present

Meteorologist Trainee, United States Forest Service, 2012-2016

Research Assistant, University of Georgia, 2010-2012

Research Scientist, Center for Ocean-Atmospheric Prediction Studies (C.O.A.P.S), 2006-2010

Recent Publications (since 2015)

Miller, P.W., Williams, M., Mote, T. (2021): Modeled Atmospheric Optical and Thermodynamic Responses to an Exceptional Trans-Atlantic Dust Outbreak. Journal of Geophysical Research (In Production)

Terando, A., Hires, J.K., Williams, M., Goodrick, S.L., O'Brien, J.J (2021): Is there a dry season in the Southeast US?. Global Change Biology, Vol. 27, 4, pp. 713-715

Haupt, S., B. Kosovic, S. McIntosh, F. Chen, K. Miller, M. Shepherd, M. Williams, and S. Drobot (2019): 100 years of Progress in Applied Meteorology. Part III: Additional Applications. AMS Monographs, Vol 59, pp. 24.1-24.35

Williams M., Stegall C., Madden M, Shepherd J.M. (2017) Mapping the Spatio-temporal evolution of Irrigation in the Georgia Coastal Plain. PE&RS, Vol. 83, 1, pp. 57-67, DOI: https://doi.org/10.14358/PERS.83.1.57

Williams, M.D. (2016). The Spatio-Temporal Evolution of Irrigation in the Georgia Coastal Plain: Empirical and Modeled Effects on the Hydroclimate. Doctoral Dissertation, University of Georgia, Athens, GA. 161 pp. http://hdl.handle.net/10724/36928

Williams M, Goodrick S, Grundstein A, Shepherd J.M (2015) Comparison of dew point temperature estimation methods in Southwest Georgia. Physical Geography. DOI: 10.1080/02723646.2015.1011554

Awards and Grants

2018 ESRI Award for Best Scientific Paper in Geographic Information Systems

Awarded best scientific paper for publication "Mapping the Spatio-Temporal Evolution of Irrigation in the Coastal Plain of Georgia, USA. Presented by ASPRS

2017 USFS Request for project funding **$50,000/2 years**

Awarded project funding for joint venture agreement with the University of Georgia; Project title: The role of climate in the 2016 Southern Appalachian wildfire season

David Hotz, NOAA - National Weather Service

David G. Hotz has been the Science and Operations Officer at WFO Morristown since June 2005. He began his NWS career at the Weather Service Office at Bristol, Tennessee in August 1986, and then transferred to the Agricultural Weather Service Center (AWSC) Stoneville, Mississippi as an Agricultural Forecaster in January 1988. In December 1990, he transferred to the National Weather Service Office at Amarillo, Texas as a Journeyman Forecaster, and then to the Weather Forecast Office at Morristown, Tennessee as a Senior Forecaster in September 1994. His interests include developing local computer applications, northwest flow snowfall, severe storms, and local climatological studies. He has a B.S. degree (1986) in Agricultural Meteorology from Purdue University.

Danny Gant, NOAA - National Weather Service

Charles D. Gant has been a Senior Forecaster at WFO Morristown since March 2018. He began his career as a Student Career Experience Program (SCEP) employee at WFO Nashville in the summer of 2009, and was then promoted to Meteorologist Intern at WFO Memphis in May of 2010 upon graduation. In March of 2013 he was promoted to General Forecaster at WFO Greenville/Spartanburg South Carolina where he remained until accepting his current position. His interests include Geospatial Intelligence, software development, severe convection, flash flooding, and winter weather. He has a B.S. degree

(2010) in Meteorology from Western Kentucky University as well as a M.S. degree (2019) in Environmental Geosciences from Mississippi State University.

Jeremy Buckles, NOAA - National Weather Service

Jeremy L. Buckles has been a Lead Forecaster at the National Weather Service in Morristown, Tennessee since December 2020. He began his career at the National Weather Service in Morristown, Tennessee as a meteorologist in 2016. His interests include severe weather, impact-based decision support services (IDSS), radar meteorology, social sciences in meteorology, and local climate studies of the Tennessee Valley and Southern Appalachians. He has a B.S. degree (2013) and a M.S. degree (2015) in Meteorology from Mississippi State University.

Matt Anderson, NOAA - National Weather Service

Matthew E. Anderson has been a Lead Forecast at the National Weather Service in Huntsville, Alabama since August of 2020. He began his career at the National Weather Service Office in Topeka, Kansas in November of 2010. He was then promoted to Journey Forecast at the National Weather Service Office in Birmingham, Alabama in February of 2012. He was then promoted to Lead Forecast at the National Weather Service in Morristown, TN in October of 2015. HIs interests include programming computer applications, severe weather, warning methodology, messaging impacts to the general public, radar meteorology, and local climate studies. He has a B.S. degree (2008) in Meteorology from the University of South Alabama and a M. S. (2010) in Atmospheric Science from the University of Alabama in Huntsville.

6. References

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7. Budget Justification

Virginia Tech, August 1, 2021 - July 31, 2022 ($13,939)

Undergraduate Research Assistant Salaries and Benefits ($5712) - Research support is requested for two undergraduate research assistants to conduct the self-organizing map research objectives (4 and 5) as well as post-processing and visualization of the WRF-ARW output. Each research assistant will work 8 hours/week for 15 weeks in fall 2021 and 13 weeks in the spring 2022 at $12.75/hour (2 researchers X 28 weeks X 8 hours/week = 448 hours total X $12.75/hour = $5712).

Travel Support ($3000) - Support is requested to partially defray the travel cost for investigator Ramseyer to present the research at the 100th Annual Meeting of the American Meteorological Society (January 2022, Houston, Texas). Additional support is requested to defray the travel cost for the two undergraduate students to present their research at the 2022 AMS Annual Meeting and/or the NWS Southern Appalachian Weather and Climate Workshop tentatively scheduled for the Spring of 2022.

Indirect Cost ($5227) - The indirect cost is 60% of the Total Direct Cost (TDC). This rate has been federally negotiated and approved by Virginia Tech's Federal Cognizant Agency, ONR.

Contributed Time - One principal investigator, Ramseyer contributing >250 hours (August 2021-July 2022)

Donation of High-Performance Computing Time - investigator Ramseyer and Virginia Tech are donating roughly 65,000 core hours per case study on the Tinker Cliffs cluster at the ARC at VT. If 25 case studies are completed by the end of the funding period, for example, the donation would represent 1,625,000 core hours.

National Weather Service (August 1, 2021 - July 31, 2022)

Publication Costs ($2500) - Support is requested to partially defray the cost for publishing one project-related manuscript in an American Meteorological Society journal.

United State Forest Service (August 1, 2021 - July 31, 2022)

No funding be sought through this proposal, although investigator Williams will be donating research time.

Contributed Time - Williams contributing > 150 hours (August 2021-July 2022)

Project Budget Page

	COMET Funds	NWS Contributions
University Senior Personnel		
1. Craig Ramseyer		**NA**
2.		**NA**
Other University Personnel		
1. Undergraduate researcher 1	**2,856**	**NA**
2. Undergraduate researcher 2	**2,856**	**NA**
Fringe Benefits on University Personnel	**NA**	**NA**
Total Salaries + Fringe Benefits	**5,712**	**NA**
NWS Personnel		
1. David Hotz	**NA**	30 hours
2. Charles (Danny) Gant	**NA**	30 hours
3. Jeremy Buckles	**NA**	20 hours
4. Matt Anderson	**NA**	20 hours
Travel		
1. Research Trips		
2. Conference Trips	**3,000**	
3. Other		
Total Travel	**3,000**	
Other Direct Costs		
1. Materials & Supplies		**NA**
2. Publication Costs (put in the NWS column if a co-author will be an NWS employee)		**2,500**
3. Other Data		
4. NWS Computers & Related Hardware	**NA**	
5. Other (specify)		
Total Other Direct Costs		
Indirect Costs		**NA**
1. Indirect Cost Rate	**5,227**	
2. Applied to which items?	**Undergraduate salaries**	
Total Indirect Costs	**5,227**	**NA**
Total Costs (Direct + Indirect)	13,939	2,500

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		3/1/2021
2. Did NWS office consult Scientific Services Division (SSD) staff?	X		3/15/2021
3. Was Statement of Work and budget formulated as a team effort between university and NWS staffs?	X		3/15/2021
4. Was proposal submitted to SSD for review?	X		3/15/2021
5. Did SSD forward copies of proposals dealing with WSR-88D data to Radar Operations Center (ROC), Applications Branch Chief for review?	N/A		
6. Did SSD forward copies of proposals dealing with hydrometeorology to the Senior Scientist of National Water Center (under NWS Office of Water Prediction) for review?	N/A		
7. Did SSD review the data request for project to ensure its scope and criticality for proposal?	X		4/1/2021
8. Is all data for the project being ordered by NWS offices through the National Center for Environmental Information (NCEI) (ncei.info@noaa.gov) free of charge?	X		3/15/2021
9. Does budget include publication charges and travel costs for NWS employees to present results at scientific conferences?	X		4/1/2021
10.Does budget separate NWS costs into fiscal year costs and university costs into calendar year costs?	X		4/1/2021
11.Does proposal include a separate justification for university hardware purchases which are usually not funded by the COMET Outreach Program?	X		4/1/2021
12. Have the following people signed off on the proposal cover sheet: - MIC/HIC? - SSD Chief? - Regional Director?	X		4/28/2021
13. Is a letter of endorsement signed by regional director attached?	X		4/28/2021

NWS Checklist for Submitting a COMET Outreach Proposal

Actions after Endorsement by NWS	YES	NO	DATE
1. University submits proposal to the COMET Program.	X		5/1/2021
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 NWS Office of Science and Technology Integration (OSTI).			
5. The COMET Program allocates funds for university.			
6. OSTI obligates funds for NWS offices.			
7. SSD/NWS office orders data from NCEI.			
8. NWS office or SSD calls OSTI for accounting code for expenses.			
9. NWS office sends copies of all travel vouchers and expense records to OSTI.			
10. NWS office or SSD sends copies of publication page charge forms to OSTI.			
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

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service Southern Region Headquarters
819 Taylor Street, Room 10E09
Fort Worth TX 76102

April 29, 2021

MEMORANDUM FOR: Ms. Lorrie Alberta
COMET Outreach Program Administrator
3085 Center Green Drive
Boulder CO 80301

FROM: Mike Coyne, Acting Director
NWS Southern Region Headquarters

SUBJECT: Letter of Support for COMET Partners Proposal

The National Weather Service (NWS) Southern Region Headquarters (SRH) enthusiastically supports the COMET Partners proposal titled "High Resolution Numerical Modeling of Mountain Wave Wind Events in the Southern Appalachians Mountain Region." Dr. Craig Ramseyer, Virginia Tech, and Dr. Marcus Williams, USDA US Forest Service will collaborate with WFO Morristown Science and Operations Officer David Hotz and other meteorologists to explore high wind events that are impactful to many NWS offices.

The vision of the NWS includes a Weather-Ready Nation plan to support a society that is prepared for and responds to weather-dependent events. Despite advances in forecast accuracy and warning lead time in recent years during mountain wave-induced high wind events, there is still a great deal of uncertainty in predictions of the strength, duration, and areal extent of the damaging winds.

The primary objective of this proposal is to improve the forecasters' understanding and predictions of extreme mountain wave high wind events in the Southern Appalachian Mountains and Foothills. This greater understanding will allow forecasters to better message the impacts of these events to our core partners, public, and stakeholders. The project will leverage fire weather researchers to increase forestry community preparedness for mountain wave high wind events.

I fully encourage and support the collaboration between NWS WFO Morristown, USDA US Forest Service, and Virginia Tech. This proposal has the potential to deliver valuable insights that could be used by a number of NWS offices in the region to address the societal impacts of mountain wave damaging winds.

Thank you for considering this proposal.