MEMORANDUM OF AGREEMENT

AMONG THE

UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

ACTING ON BEHALF OF THE

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

AND THE

NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

AND THE

OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

FOR

CO-DEVELOPMENT OF COMMON MODELING INFRASTRUCTURE

1) Overall Goal of this Memorandum of Agreement

This Memorandum of Agreement (MOA) will create a strategic relationship of mutual benefit for developing the infrastructure to enable broader community engagement in improving the Nation's weather/climate modeling capabilities for operational and research applications. The Parties are the infrastructure developers from the National Center for Atmospheric Research (NCAR), and the National Weather Service (NWS) and Office of Oceanic and Atmospheric Administration (OAR) of the National Oceanic and Atmospheric Administration (NOAA). The "broader community" refers to researchers from universities and other laboratories that use and develop these modeling capabilities.

2) Legal Authority

33 U.S.C. §883d, which authorizes NOAA to conduct investigations and research in geophysical sciences.

33 U.S.C. § 883e, which authorizes NOAA to enter into agreements with any public or private organization and to establish the terms of any agreement entered into under this section.

15 U.S.C. § 313, which provides organic authority for NOAA's meteorological activities.

3) Background

A Letter of Intent (LoI) signed July 28, 2017 expresses the intent of NCAR and NOAA to develop this Memorandum of Agreement (MoA) describing how the Parties will work collaboratively toward the design and construction of modeling infrastructure that will take into consideration the requirements of the broader community of modelers. NCAR and NOAA are following similar paths toward unified modeling capabilities across spatial and temporal scales for research and development (R&D). Moreover, NCAR research, NOAA's R&D and operational modeling groups, and the broader community share many requirements in the areas of prognostic models, observations, and data assimilation. With this in mind, there is potential mutual benefit from strategic collaboration.

In pursuit of its varied missions and following recommendations of external reviews of the operational forecast systems, NOAA is moving to a Unified Forecast System (UFS). The UFS is intended to be a community coupled ensemble-based physical environmental forecast system that can be applied on time scales ranging from nowcasts to climate projections, with regional to global domains appropriate for each application. The UFS will use a modular architecture, with workflow components (pre-processing, data assimilation, post-processing etc.) and component models (for example, for the atmosphere, ocean and sea-ice) that can be used and developed either as coupled or stand-alone models. Many of the component models that are intended for integration in the UFS are already community models with the notable exception of the global atmospheric model. Making the later a community model is being addressed in the Next Generation Global Prediction System (NGGPS) project. Making the UFS a community model requires the development of infrastructure capabilities as outlined in Section 5, below.

The relevant imperative in the NCAR 2014-2019 Strategic Plan is to, "Develop, deliver and support a suite of advanced community models." The NCAR Strategic Plan seeks to accelerate advances in these community models by incorporating improvements from community research and by enhancing coupling capabilities. A cornerstone of the NCAR strategy is the pursuit of a unified community modeling (UCM) approach to support global models with limited-area, higher-resolution meshes for both regional downscaling and upscaling of information from local events. Hereafter, the term NCAR UCM will be used as a placeholder to refer to this approach until a formal project is launched. Although the science requirements are still being established with community input, the basic infrastructure needs are understood and development has begun.

Thus, both NOAA and NCAR are adopting a unified approach to coupled environmental modeling, the success of which is critically dependent upon community contributions. For the research community to be fully engaged, the infrastructure needs to enable rather than inhibit participation. This implies that the modeling system needs to be state-of-the-art, well documented and easy to use for both operations and research. Benefits of collaboration on common infrastructure include:

- Efficiencies and synergies gained by working as a partnership in a common modeling infrastructure and thus reducing duplication of effort;
- Common community code repositories, so that future advances by the research community can more easily and quickly benefit the operational community, and vice versa; and

- Ease of community access to NOAA's operational models and tools as well as leveraging NCAR experiences with supporting the Community Earth System Model (CESM) and Weather Research and Forecasting (WRF) model as community models, for example.

For transparency regarding the feasibility of operational implementation of new approaches, the NWS will publish operational constraints and a description of how the agency will make decisions regarding operational implementation of both the infrastructures discussed herein and the component models in the UFS.

4) Scope

This MOA focuses on infrastructure common to the NOAA UFS and the NCAR UCM. The key elements of this infrastructure to be considered jointly are identified and discussed in Section 5, below. Section 6 addresses actions for the participants that will allow collaboration of their respective efforts. Section 7 addresses coordination for implementing this MOA and provides a broad approach on areas of collaboration and responsibilities. This MOA thus provides a high-level agreement, the implementation of which will be addressed in annual work plans or implementation agreements, and is intended to provide for the governance necessary for NOAA and NCAR to set joint priorities and leverage and marshal resources.

The MOA does not seek to exchange funding between organizations, or to commit to new funding for collaborative work, but seeks to coordinate existing and ongoing investments of the parties relevant to this MOA. This MOA does not replace existing governance structures of the Parties, but encourages coordinating within existing governance to ensure alignment with unified coupled community modeling.

5) Defining Infrastructure

NOAA and NCAR agree the following are seven key elements of common infrastructure for the UFS and UCM, based on their collaborative and independent processes to date. The background of each element outlines the current state of affairs, including significant ongoing collaborations that are the foundation of shared objectives.

a) Coupling between Components: Inter-Component Coupling

Background: The UFS architecture uses the Earth System Modeling Framework (ESMF) architecture, the National Unified Operational Prediction Capability (NUOPC) Layer to standardize interfaces, and the NOAA Environmental Modeling System (NEMS) mediators for coupling component models (e.g., an atmospheric model with on ocean model). The NCAR UCM is adopting a similar approach, based on more than a year of regular discussions with NOAA. ESMF and NUOPC are well-established community software packages. NCAR and NOAA have developed an initial design for a Community Mediator for Earth Prediction Systems (CMEPS) as a new framework for inter-component coupling of community models, which originates in NEMS. CMEPS is being designed as a single NUOPC-based infrastructure that can ultimately accommodate EMC/NEMS, NCAR/CESM/WRF/MPAS and OAR/GFDL/FMS model coupling strategies.

Objective: Develop, support and maintain a common CMEPS mediator that can ultimately accommodate evolving EMC, NCAR and GFDL model coupling strategies and thereby facilitate community research contributions and accelerate transition of research into operations.

b) Coupling within a Component: Intra-Component Coupling

Background: The Next Generation Global Prediction System (NGGPS) project and the Global Model Test Bed (GMTB) are implementing the Common Community Physics Package (CCPP) in NOAA's operational atmospheric model(s). NCAR is exploring a similar capability (the Community Physics Framework, CPF). NOAA and NCAR have concluded that the CCPP framework satisfies many NCAR requirements, paving the way for a collaborative CCPP / CPF approach for the UFS and the UCM.

Similar physics interfaces are or have been developed for other component models such as wave, ice and ocean models. Moreover, intra-component coupling could address direct use of dynamics and physics approaches across component models, for instance integrating ice physics in ocean models and integrating aerosol and atmosphere dynamics. Such approaches are expected to become important at a later stage driven by performance, stability and other scientific evidence.

Objective: Develop, support, and maintain a flexible framework for a common interface that allows interoperability / integration of physics packages, initially focusing on community atmospheric models.

c) Workflow: Scripting Infrastructure

Background: The term "workflow" here refers to all infrastructure, code and datasets (e.g. initial conditions) needed to configure, build and run an end-to-end forecast system utilizing a coupled model for a specified application.

The community development and use of NCAR community models is enabled by a well-documented and user-friendly workflow infrastructure known as CIME (Common Infrastructure for Modeling the Earth). One part of CIME is its Case Control System (CCS) which contains the scripts to run forecasts with a single-executable coupled Earth System Model. The CCS is portable, flexible and provides provenance and reproducibility of configurations, thus making coupled Earth System Modeling easily accessible in the face of increasing complexity.

EMC is embarking on the creation of a Community Research and Operational Workflow (CROW) to replace the existing myriad of model dependent workflows. CROW is intended to unify development and operations within NCEP, and to provide a portable workflow approach for the larger community. CROW is critical to both NCEP and community development of operational codes because it will minimize the need for re-engineering of external contributions to operations. The CIME/CCS functionality represents a critical aspect needed in CROW.

Objective: Develop support and maintain a common workflow infrastructure using a CROW / CIME-CCS based approach to facilitate community research and accelerate the adaptation of new research into operations.

d) Quality Assurance Testing in Model Development

Background: Testing is critical to ensure the software quality for newly added code, to assure that modified code is robust and performs as expected, and to address if differences in model runs are within expected ranges for intrinsically chaotic model components. Testing should encompass the following:

- Regression testing to demonstrate backwards compatibility and previous basic functionality such as bit-for-bit restarts.
- Hierarchical unit to system testing to document the impact of software development.
- Statistical testing of chaotic initial value aspects of coupled models to address if model differences are acceptable (porting etc.) / significant (development).

CIME contains these quality assurances (QA) which are essential for NCAR community modeling. The CSS could be adapted for NOAA UFS to accelerate the transition to operations, and to NCAR UCM in order to bridge the weather/climate interface, by providing common testing for both research and operations. Unit testing for new implementations in NOAA Operations are followed by full-system evaluations using a suite of retrospectives as well as real time parallels to evaluate impacts of model upgrades. This is followed by a 30-day technical test period prior to implementation. Although it is not expected that this level of QA be used for the UFS, it should be kept in mind that this level of rigor will be required for UFS components moving into NOAA Operations.

Objective: Provide full regression testing with each software module developed as part of this MoA. Develop, support and maintain common hierarchical and statistical testing approaches, with a goal of establishing a common software infrastructure for QA.

e) Forecast Verification: Comparison to Observations

Background: The Model Evaluation Tools (MET) software package was developed at NCAR to address the general need for model evaluation and to provide the scientific community with a comprehensive set of tools for diagnostic evaluation of Numerical Weather Prediction (NWP) and possibly climate prediction systems. MET is a community-supported software package that is used extensively by both users and developers of NCAR community weather models and to a more limited extent by climate modelers. NOAA has committed to unify all its internal verification around MET, with the acknowledgement that MET needs to be expanded to address other environmental component models (ocean, waves, sea-ice, etc.). Evaluation packages for these components exist at NCAR and GFDL to support their coupled climate models and could become the basis for coupled forecast model evaluation within MET.

As with (d) above, using the same toolkits in research and operations, as well as in weather and climate, reduces duplication of work and accelerates the transition from research to operations. Traditionally, verification focuses on the most forecast-relevant output, such as pressure, wind speed and precipitation. To support sustained improvement of coupled operational models, and to make verification more relevant for

research, the verification needs to be expanded to include output relevant to coupled processes. Shared metrics enable evidence-based decision making for operations.

Objective: Develop, support, and maintain common verification toolkits for UFS and UCM components and coupled models, in both research and operational forecast modes.

f) Software Repository Management

Background: Effective community development of software requires open access repositories. NCAR UCM will use Git/GitHub for collaborative development, and NOAA has recently formulated a formal policy for using GitHub for NOAA software. Considering this, all infrastructure and supporting code developed under this MoA, will reside in GitHub repositories. The management of these repositories will be set up to enable collaborative development across the wider research community, and will include governance, quality assurance, and workflow tools as described under *c)* as well as support described under *g)*. It will allow the addition of science from other repositories to be easily added. Additional data needed to run models (for instance, configuration and validation data, initial and boundary conditions) will generally not reside in repositories, but need to be as easily accessible.

Objective: Maintain and develop the common infrastructure covered by this MoA in publically accessible GitHub repositories that are communally managed for both NOAA UFS and NCAR UCM purposes. A list of main software packages thus covered is found in Section 6.

g) User / Developer Support

Background: NCAR has prioritized the development of infrastructure associated with user support of NCAR community models. In particular, for CESM this includes the availability of extensive model documentation, multiple web accessible databases for planning, porting, testing and experiment provenance, on-line tutorial, and direct user support via the DiscussCESM fora. New users are encouraged to register for the forums so that they can participate in topics related to their areas of interest.

NOAA is supporting the Developmental Testbed Center (DTC) to stand up support for the UFS. The initial user support framework focuses on the Convection Allowing version of the UFS and will be based on the existing protocols used to support the Community Gridpoint Statistical Interpolation (GSI) system/Community Ensemble Kalman Filter (EnKF) data assimilation system and the Hurricane Weather Research and Forecasting model (HWRF). This framework will include a code management plan that addresses how community contributions can make their way into the code repository and testing protocols, code release procedures (including the need to address code portability), a Users' Guide, scientific documentation and helpdesk support. NOAA is seeking to develop a long-term vision for how to most effectively address user support for all applications of the UFS. In the short-term, NOAA/EMC will be providing limited support for the the FV3-based global model.

Objective: Provide active and passive user support for the UFS and UCM, leveraging existing practices and protocols developed for the CESM, GSI and HWRF.

6) Collaboration

NCAR and NOAA each have distinct strategic priorities rooted in their missions, and in that context are already investing in activities relevant to this MOA.. Within the limits of their available resources and their individual mandates, the Parties will focus their efforts for coordination and collaboration on the following components:

a) NEMS / CMEPS unification as outlined in Section 5.a

b) CCPP / CPF unification as outlined in Section 5.b

c) CIME – CROW unification and development as outlined in Section 5.c

d) Unified testing to assure code is robust and performs as expected, as outlined in Section 5.d

e) MET development and expansion to application for fully coupled systems as outlined in Section 5.e

f) Github based repositories for all infrastructure software as outlined in Section 5.f

g) Leveraging, creating if necessary, or adapting support capabilities at NCAR and DTC as outlined in Section 5.g.

7) Resources and Prioritization

This MOA establishes the need for joint coordination to advance collaborative development efforts to create common infrastructure. Each organization is responsible for managing its own resources, but will coordinate their work plans for each collaborative development. The MOA will be implemented using coordinated annual work plans. NOAA and NCAR acknowledge that all coordination, including work plan development, needs to be aligned with Parties' priorities and resource availability. Hence, annual work plans will be approved by program management for their respective organizations. In addition, there will be no pooling of funds. All funding will be applied to discrete tasks with discrete deliverables unique to that funding. The overall integration of the development activities will be accomplished by joint coordination, defined in Section 8, below.

8) Coordination

The external community is heavily involved in guiding NCAR's community modeling endeavors through various advisory boards, steering committees, workshops, and working groups. There also is an external presence assisting with the governance of NOAA's UFS, through the newly formed UFS Steering Committee, including a co-chair, the Technical Oversight Board, and Strategic Implementation Working Groups. NCAR and NOAA recognize that governance is in place for many of the subcomponents in the UFS and UCM, including some of the infrastructure components discussed here.

These NCAR and NOAA governance processes are responsible for establishing respective research and operations requirements and priorities that subsequently map to infrastructure deliverables. Coordination is needed, specific to the collaborative infrastructure elements defined above, to manage progress toward agency goals while

maximizing infrastructure compatibility between NOAA and NCAR. This coordination will be distinct from NOAA and NCAR unified model governance, but must consistently coordinate with such governance bodies to legitimize the collaborations outlined in this MOA. The coordination for each infrastructure element will define and identify the necessary resources for that element in addition to monitoring progress and working to resolve, whenever possible, potential software incompatibilities that may arise. Details of the coordination will be established as part of the implementation of the MOA and will need to align with NOAA's annual funding authorization and NCAR's Operating Plan.

9) Limitations

This MOA will be valid for five years from date of signature, unless it is renewed, revised, or extended upon mutual consent. This MOA can be cancelled by either party upon 90 days written notice. The Parties will bear their own costs.

10) Notices

All written notices between the parties with reference to this MOA shall be sent to the respective address of the party, or to such other individuals as the parties may designate in writing from time to time, as follows:

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FOR UCAR/NCAR

Antonio J Busalacchi Date: 11/6/18

Dr. Antonio J. Busalacchi, President, UCAR

Vanda Grubišić Date: 10/31/18

Dr. Vanda Grubišić, Interim Director, NCAR

FOR NOAA

Louis W. Uccellini Date: 12/20/18

Dr. Louis W. Uccellini, Assistant Administrator for Weather Services NOAA, and Director, National Weather Service

Craig McLean Date: 1/30/2019 cm

Mr. Craig McLean, Assistant Administrator, NOAA Oceanic and Atmospheric Research