Project Plan and Charter for

Global Ensemble Forecast System (GEFS) V12.0.0

Development and Transition to Operation

VERSION 0.0 (DRAFT)

06/05/2019

U.S. Department of Commerce (DOC)
National Oceanic and Atmospheric Administration (NOAA)
National Weather Service (NWS)
National Centers for Environmental Prediction (NCEP)

Environmental Modeling Center (EMC) &
NCEP Central Operations (NCO)

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NCEP Project Plan and Charter	
Implementation of Global Ensemble Forecast System (GEFSv12), Q4FY2020	
Effective Date: Date of last signature **Responsible Organizations: NWS/NCEP/EMC & NCO**	**GEFS V12.0.0 Plan v 0.0**

SIGNATURE PAGE

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NCEP Project Plan and Charter

Implementation of Global Ensemble Forecast System (GEFSv12), Q4FY2020

Effective Date: Date of last signature **GEFS V12.0.0 Plan v 0.0**
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NCEP Project Plan and Charter

Implementation of Global Ensemble Forecast System (GEFSv12), Q4FY2020

Effective Date: Date of last signature **GEFS V12.0.0 Plan v 0.0**
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1. Introduction

The National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) has the responsibility to provide weather, water, and climate information to protect life and property, and enhance the national economy. The NWS mission is to provide the best possible guidance to a wide variety of customers, including emergency managers, forecasters, and the aviation community. The Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP) is primarily responsible for working with several partners in developing, maintaining, enhancing and transitioning-to-operations numerical forecast systems for weather, ocean, climate, land surface and hydrology, hurricanes, and air quality for the Nation and the global community and for the protection of life and property and the enhancement of the economy. The mission objectives include being the world's best and most trusted provider of deterministic and probabilistic forecast guidance across all spatial and temporal scales. Fundamental and central to this mission is the global numerical weather prediction system developed and maintained by the Modeling and Data Assimilation Branch (MDAB) of EMC with support from Verification, Post-Processing, Product Generation Branch (VPPGB) and Engineering and Implementation Branch (EIB). Major applications of the global modeling system include the high resolution deterministic medium range Global Forecast System (GFS), the Global Ensemble Forecast System (GEFS), and the atmosphere-ocean-ice coupled Climate Forecast System (CFS). Apart from providing forecast guidance over different time scales, the global model also provides data for initial conditions and boundary conditions driving various downstream applications including high-resolution regional atmosphere, hurricane, ocean, wave, space weather, and air quality models, and a wide range of products to various service centers, Weather Forecast Offices (WFOs) and other stakeholders. To properly serve the customers, the forecasts must be made available reliably and at the appropriate time within available resources.

As part of the Next Generation Global Prediction System (NGGPS) program, the National Weather Service (NWS) Environmental Modeling Center (EMC) along with other national labs and academia were funded to develop and upgrade Global Ensemble Forecast System (GEFS) and to extend the system to week 3&4 forecast.

As part of the Next Generation Global Prediction System (NGGPS) program initiative and broad support from the community, NCEP/EMC replaced the spectral semi-lagrangian reduced Gaussian-grid hydrostatic dynamic core of the current operational GFS with the non-hydrostatic Finite Volume Cubed-Sphere (FV3) dynamic core developed at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) for its scientific integrity and computational performance. Another major change to GFS is the implementation of a new microphysics scheme developed at GFDL, which is expected to improve the modeling of clouds and precipitation. GFS v15.1, implemented operationally on June 12, 2019, is the first operational configuration of the model with the FV3 dynamic core and GFDL Microphysics. This modeling system provides a fundamental early building block for the emerging Unified Forecast System (UFS) that is envisioned as a full community-based Earth-System model. The NOAA Environmental Modeling System (NEMS) framework is providing the infrastructure for unifying and coupling the global system to various components to create the UFS. As such, GFS v15.1 is the first instantiation of UFS in operations, and will form the basis for migrating and unifying NCEP Production Suite (NPS) with different UFS configurations, allowing the same code base to be used for community research and operations.

The Global Ensemble Forecast System (GEFS) will use the same foundational framework (NEMS) and FV3 based atmospheric modeling system for providing probabilistic ensemble forecasts, for the for the first time, GEFS will extend the forecast length to weeks 3&4, entering into sub-seasonal forecast time scales.

The objective of this project plan is to document the GEFS v12 development activities, milestones, deliverables, and resources needed to perform these activities.

The major upgrade of the GEFS (GEFS v12) is expected to be in the area of model physics along with increased horizontal resolution and increased ensemble membership, and coupling the atmospheric model with the current operational Global Wave Ensemble System (GEWS) based on WaveWatchIII and the aerosol and chemistry components based on GOCART. The atmosphere-wave-aersol/chemistry coupling enabled by the NEMS infrastructure will also address the objectives of simplifying the NPS by reducing the number of independent modeling systems in operations.

This project plan documents the requirements, procedures, milestones and timelines for the upgrade cycle of GEFS v12.0.0 leading to the operational implementation scheduled for Q4FY2020. This project describes utilizing NEMS based UFS infrastructure towards unifying the NCEP deterministic global atmospheric model, global wave model, and the aerosol/chemistry module. This project plan and charter between EMC and NCO was created to address communication and expectation between EMC and NCO in preparation for the GEFS v12 implementation.

1.1 NGGPS Program Description

Information of the Next Generation Global Prediction System (NGGPS program at the National Weather Service (NWS) can be found at: https://www.weather.gov/sti/stimodeling_nggps

1.2 Global Ensemble Forecast System Description

Ensemble predictions are increasingly being used for providing situational awareness of high-impact weather forecast events, informing the forecaster of the range of possible weather scenarios. Ensembles are now also commonly used to provide estimates of forecast-error covariances in data assimilation methods.

There are two sources of forecast uncertainty in ensemble prediction systems. The first is initial-condition uncertainty. An ensemble should be initialized with samples from the distribution of plausible analysis states. The second is model uncertainty, which can bias the mean forecast and limit the spread of simulations, resulting in an overconfident ensemble, especially for surface-related variables (e.g., surface temperature and precipitation) and tropical forecasts such as hurricane tracks. These contributions to forecast error can be attributed to model deficiencies as well as from deterministic assumptions built into the forecast models' components, such as parameterizations.

Addressing the former challenge, initial-condition uncertainty, has progressed in the past+ ecent years more than the latter, model uncertainty. With ensemble Kalman filters and hybrid methods, there is now a direct method for sampling analysis uncertainty. The accuracy of such methods, however, depends critically on ensemble size, the treatment of model uncertainty in the data assimilation cycle, the extent of non-linearity/non-Gaussianity of error statistics, and the chosen methods for dealing with position errors of coherent features.

Model uncertainty treatments are less advanced. Researchers are seeking ways of ameliorating forecast bias and increasing forecast spread that are physically realistic. Lacking these, they also seek appropriate methods of post-processing the forecast guidance to ensure that it is as bias-free, skillful, and reliable as possible.

need a website with good description of GEFS in general

2. Objective and Scope

Need description for the objective and scope for GEFS v12

2.1 Known Strengths and Deficiencies of GEFS V11

Need description

2.2 Expected Benefits from GEFS v12.0

Add description, including coupling to wave ensemble and aerosol/chemistry

- Computation cost (example)

- GEFSv10 – ~105 nodes for 1 hour (one cycle) - 52km (day 1-8)
- GEFSv11 - ~150-300 nodes for 1 hour (one cycle) – 34km (day 1-8)
- Nearly 2-3 times resource increasing for upgrade (higher resolution)

- Benefit and improvement (based on 2-year + retrospective runs)
  - Approximate 8-hr useful forecast skill (60%) improvement based on NH 500hPa height AC score
  - Approximate 10% error reduction over all for 72 hours Tropical Storm track forecast from last 4 summer season statistics
  - Approximate 12% error reduction for NA 24 hours surface temperature forecast after bias correction (final products)
  - Approximate 8% BS skill improvement for CONUS PQPF 36-72 hours forecast great than 5mm/24 hours
  - Approximate 8% increasing "hits" for extreme cold weather events for 96 hours forecast with the same "false alarms"
- Unification/coupling to wave ensemble and aerosol/chemistry
  -

2.3 Metrics for evaluation

Metrics for evaluation of individual components include but are not limited to the following:

Weeks 1 & 2:

- fcst and obsv counts for various probabilities (binned by 1/members+1) based on which reliability plots are generated
- Hit rates and false alarm rates (binned by 1/members +1) based which ROC curves are generated
- RPS, RPSf, RPSc, RPSS (f refers to fcst, c refers to climatology)
- CRPS, CRPSf, CRPSc, CRPSS
- BS, BSf, BSc, BSS, BS-reliability component, BS-resolution component, BS-climatology component (uncertainty), BS-low, BS-high,
- Spread, RMSE, Mean Error, Absolute Error Probability Anomaly Correlation (PAC)
- Histogram
- Relative Position (closest-to-observation member counts)
- Economic Value

Weeks 3 & 4:

- Anomaly correlation: T2m, Prate, Tropical SST, Nino 3.4 SST, Nino 3.4 Prate, 500mb

- Collaboration needed with CPC to determine other metrics and verification tools

Waves:

- TBD

2.4 Scientific upgrades for GEFS v12.0

Upgrades for the GEFS V12.0 include the following science changes for the atmospheric, wave, and chemistry models.

Update for GEFS v12

Science changes for the atmospheric model component
1. Model resolution: 3. Advanced physics chosen from Physics Test Plan: • Planetary Boundary Layer/turbulence: K-EDMF => sa-TKE-EDMF • Land surface: Noah => Noah-MP • Gravity Wave Drag: separate orographic/non-orographic => unified gravity-wave-drag • Radiation: updates to cloud-overlap assumptions, empirical coefficients, etc. in RRTMG • Microphysics: Further improvements to GFDL microphysics • Fine tuning of advanced physics suite consistent with increased vertical resolution
4. Coupling to WaveWatchIII
• Two-way interactive coupling of atmospheric model with Global Wave Model (GWM) • Modifications to surface physics to account for wave interactions
5. Science changes for the Global Data Assimilation
• Local Ensemble Kalman Filter (LETKF), including early cycle updates in support of GEFS • 4-Dimensional Incremental Analysis Update (4DIAU) • Add Stochastic Kinetic Energy Backscatter for atmosphere (SKEB) and introduce procedure for land/surface flux perturbations to be consistent with Stochastically Perturbed Physics Tendencies (SPPT) • Modified stratospheric humidity increments • Improved Near Surface Sea Temperature (NSST) analysis • Semi-Coupled Land Analysis as forced by observed precipitation • Improve cloud analysis by using cloud fraction in the forward model and properly treating super-cooled water clouds

6. Observation changes for the Global Data Assimilation System
● ObsProc changes (independent upgrades) ● New observations (satellite and conventional) ● Land Data (TBD) ● Others (TBD)

2.4.1 Upgrades to Atmospheric Model

revise for GEFS-Atm v12

this should include resolution, 2 tier SST, and any other science upgrade

The original plan for NGGPS implementation was expected to have increased horizontal and vertical resolution, advanced physics and data assimilation, and improved scalability. That scope was reduced in GFS v15.1 to match the current operational configuration with minimum changes except for the dynamic core and GFDL microphysics to accelerate the transition of FV3 based global model applications into operations. Model forecast skill is significantly influenced by the horizontal and vertical resolution, and other major global modeling centers are operating their global prediction systems at a much higher resolution, leaving a gap between NCEP and other centers. ECMWF, the world leader in the global NWP, operates the Integrated Forecast System (IFS) with about ~9km horizontal resolution and 137 vertical levels. UK Met Office operates their Unified Model with ~10km horizontal resolution and 70 vertical levels.

1.1.1 Model Physics Upgrades

The next implementation of the GFSv16 is expected to include significantly advanced model physics. New parameterizations for deep and shallow moist convection (CP), cloud microphysics (MP), and planetary boundary layer (PBLP)/turbulence are being considered for GFSv16. An experiment was designed to assess whether advances in GFS physics could be accelerated by introducing already-tuned CP-MP-PBLP sub-suites instead of separate CP, MP, and/or PBLP components.

2.4.2 Coupling to WaveWatchIII Wave Ensemble System

The current operational Global Wave Ensemble System (GWES) based on an implementation of the WAVEWATCH III model (WW3), will become a component of the coupled GEFSv12 system. The atmosphere-wave coupling enabled by the NEMS infrastructure will address the objectives of simplifying the NPS by reducing the number of independent modeling systems in operations.

The FV3-WW3 coupled framework for GEFSv12 was developed and tested primarily for technical compatibility, and has set the framework for expanding coupling the global wave deterministic component to other NCEP systems, such as the GFSv16. Several tests have been conducted successfully to verify the technical aspects of the one-way coupling scheme that will be adopted in GEFSv12 and GFSv16. Two-way atmosphere-wave interactions will be included in subsequent upgrade to both systems (eg, GEFSv13 and GFSv17).

More details on FV3GFS-WW3 coupled system development and test plan are documented at: https://vlab.ncep.noaa.gov/redmine/projects/emc-fv3-ww3

2.4.3 Coupling to Aerosol Model

The global aerosol system is incorporated as a separate component coupled to GFS V15 using a NUOPC cap. Technically, coupling occurs two-way, as mixing ratios of chemical tracers are exchanged between FV3GFS and GSDCHEM Aerosols at each coupling step to be advected by FV3 dynamical core. However, at this point coupling is considered to be only one way in this milestone from a scientific standpoint, since feedbacks to the meteorology are not yet activated. Additional development work, outside the scope of this project, needs to be performed within GFS to include direct and/or indirect aerosol feedbacks to the atmosphere. In particular, evaluation needs to be done on the global scale.

At each coupling time step, a complete set of fields is provided by FGFS to the Aerosol component, which includes them in chemistry computations and returns updated mixing ratios for the chemical tracers to GFS. Tracer concentrations and some diagnostic chemical output are included in GFS history files.

2.4.4 Upgrade to Wave Model

The global wave model component in GEFSv12 (henceforth GEFS-wave) will be upgraded relative to the current operational GWES, as follows. The global domain resolution will change from ½ deg to ¼ deg. Such higher resolution spatial grid will be closer to GEFS native resolution favoring coupling. To achieve better scalability in a parallel computing environment, the GEFS-wave computational grid will consist of a 3-grid mosaic with rectilinear meshes (global, Arctic and Antarctic).

The GEFS-wave forecast range will be extended from GWES current 240h, to match the GEFS 384h forecast range. Such extended forecasts will support the development of week 2 and 3 products, leveraging experimental products developed using neural networks/AI. As a consequence of coupling, GEFS-wave products will become available sooner to users. Furthermore,output products will be generated as the wave model component is integrated forward in time, and data files will be available for every output step in the forecast range, which will also streamline product delivery to users.

A detailed development and evaluation plan for the GEFS-wave component is provided at https://docs.google.com/document/d/1aeLg4H6ZtJEDtbxvPL2MnwPajfFKoL36ZlBxA61OZkM.

2.4.5 Upgrade Aerosol Model

The NEMS coupled app (FV3GFS-CHEM) includes two components: FV3GFS V15 and GSDCHEM Aerosols. The Aerosol code is a NUOPC-based chemistry component developed to replace the current NEMS GFS Aerosol Component (NGAC at 1x1°, Wang, et al. 2018). The Aerosol code is based on the NASA Goddard Operational Chemistry and Aerosol Radiation and Transport (GOCART; Chin, et al., 2007) version with modifications from the WRF-Chem (Grell, et al. 2005) chem_driver. The chemistry and aerosol modules used for GEFS Aerosols include simple sulfur chemistry, hydrophobic and hydrophilic black and organic carbon, and a 5-bin sea salt module. Additionally, included is the FENGSHA (Dong, et al. 2016) 5-bin dust module, wildfires modeling using Fire Radiative Power (FRP) and smoke emissions from the NESDIS Global Biomass Burning Emissions Product (GBBEPx; Zhang, et al., 2012). lPlume rise modeling is done with a 1d cloud model (Grell & Freitas, 2014), and, optionally, volcanic ash emissions are also included. Tracers are transported by the dynamics as well as the GFS physics (GFS PBL and Simple Arakowa Shubert (SAS) deep and shallow convection parameterization). Subgrid scale wet scavenging is done inside the two SAS routines. At this point large-scale wet scavenging is handled inside the chemistry component, based on WRF-Chem. All 2D and 3D fields exported by FV3GFS are initialized using baseline input data provided for regression testing on Hera, Cray and Dell (fv3_control).
The GEFS-Aerosols system will be run as an additional GEFS member at C384L64 resolution (~25 km) but with GOCART simple aerosol chemistry (17 species) run to only 120 forecast hours four times per day. FV3GFS-Chem currently requires 58 nodes to run 5 days in 37 cpu minutes on the Dell Phase III systems.

2.5 Potential Upgrades to Infrastructure and Products

2.5.1 Workflow

Description

2.5.2 METplus

Description

2.5.3 Repositories

Description

2.5.4 Products

Description All GEFS 2.5 degree and 1.0 degree data, along with World Area Forecast System (WAFS) 1.5 degree data and subdomains generated from the GEFS, will be proposed to be removed to the National Weather Service Mission Delivery Council (MDC) in Q1FY20. If the products are approved to be removed by the MDC, a Public Notification Statement will be issued, asking for comments from users for a 30-day period, likely also in Q1FY20. Analysis of the comments will be provided to the NCEP and EMC Director, who will then have the final decision on which products to remove, or retain. The final list for removal will be included in the GEFS v12 Service Change Notice (SCN), 30 days prior to implementation. This procedure for product removal follows the National Weather Service Instruction 1-1002 policy.

Several new products are proposed for release with GEFS v12:

1) 0.25 degree data, every three hours, out to ten days (all 590 variables as in 0.5 degree data)
2) 0.50 degree data, every three hours, out to ten days vs eight days in GEFS v11
3) 0.50 degree data, every six hours, out to sixteen days or thirty five days for subseasonal forecasts
4) Produce 76 more variables:
    a) HGT on cloud ceiling
    b) SNOWHF and SNOWC at the surface
    c) PV on isentropic levels 310K and 350K
    d) Vertical velocity on pressure levels 10, 20, 30, 50, and 70 hPa
    e) U, V, T, and PV on isentropic levels 450, 500, and 650K
    f) H, T, U, V, q, and w on 1, 2, 3, 5, 6, hPa levels
    g) H, T, P, U, V, RH on the lowest four sigma levels
5) Point forecast sounding data in BUFR format, for individual members and ensemble mean

2.5.5 GEFS downstream codes

Need description

2.5.6 System Integration *(not sure if this belongs here)*

GEFSv12 will be tested using incremental integration testing approach to confirm the system compliance with implementation requirements:

- Scientific performance test
    - Potential new feature coming into GFSv16 will be tested separately and independently.
    - GFSv16 final configuration will pick those features showing positive impact.
    - Once the final configuration is fixed, integration test will be conducted to check if the improvement remain true.
- Technical performance test:

- Scalability test (increasing # of computer tasks speeds up model integration),
- Tests for IO and coupling (to address any bottlenecks)
- Meet EE2 standards: correct data flow and control flow; timing and memory usage satisfies requirement (high watermark test) , restart capability, harness test, debug mode test
- Exception handling

- All the test procedures and results will be documented.

Anything else?

Assuming there is no changes to: in-line post, NEMS/ESMF, Libraries/Utilities

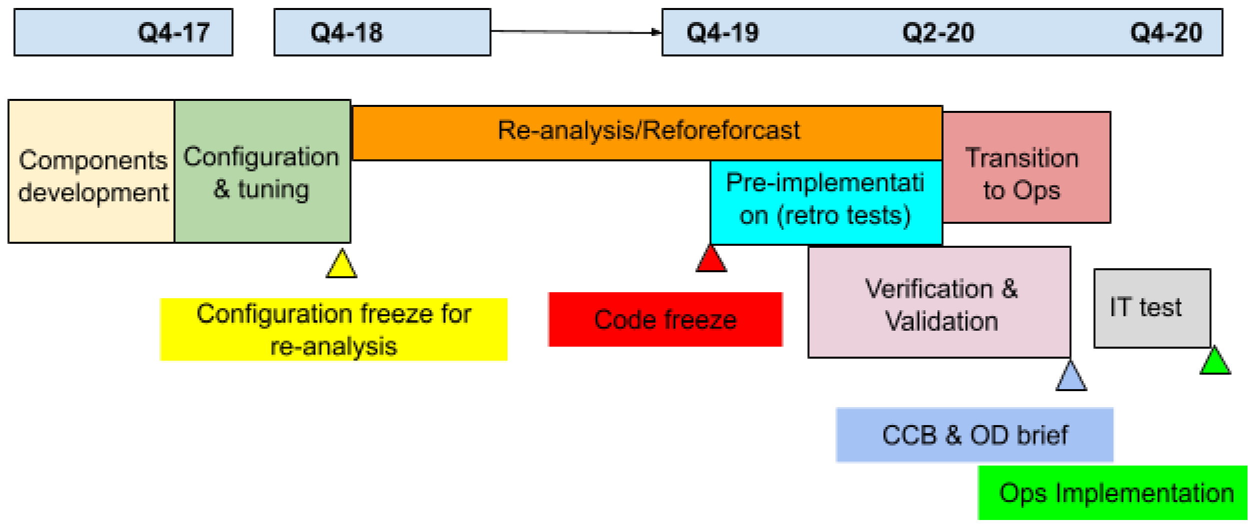
3. Project Description

3.1 Project Phases

The figure below illustrates a schematic describing the development and operational implementation cycle for the GEFS v12. The choice of scientific upgrades is dependent on various factors, including:

- Recommendations from the field to address known issues
- Research readiness and maturity of advanced scientific innovations
- Favorable results from extensive pre-implementation tests
- Availability of operational computational resources
- Favorable endorsements from the stakeholders.

Typical developmental phases of GFS are described in the diagram below.



3.1.1 Development Phase

This phase pertains to the development and testing of all potential upgrades, it can include activities such as code/algorithm assessment, test and evaluation, and interface with the operational code. Detailed information about this phase can be found in the project and test plans for each component described in Section 3.

All major potential upgrades to the GEFS components need to be incorporated into the GEFS framework at least three months prior to the start of the pre-implementation test phase to allow for fine-tuning of the entire end-to-end system.

This phase of development and tests can be performed on NOAA R&D computers such as Jet, Theia, Gaea, or on the NCEP WCOSS computer.

The following criteria is used to make decisions on upgrade component selection for inclusion into GEFS v12:

- Individual changes to the model are tested separately and independently.
- Developers start with a branch from the master version of GEFS (currently based on GEFS v12) and conduct scientific experiments either on R&D HPC or WCOSS.
- For physics upgrades, developers follow the test plan designed by MDAB Physics Group Lead. Usually the plan consists of “forecast only” experiments over a long period (for instance, every 10th day for two years) either using ECMWF analysis or GFS v15.1 analysis, and use GFS v15.1 configuration as the control. AMIP-type climate experiments running at lower resolutions are also needed for testing, for instance, the unified gravity-wave drag parameterization, to

understand its impact on certain atmospheric modes that can be assessed only in extended climate runs.

- For DA and Observing System upgrades, developers follow the test plan designed by MDAB Data Assimilation Group Lead. Usually the plan consists of running low-resolution cycled experiments for one summer month and one winter month, and use GFS v15.1 configuration as the control.
- For resolution upgrades, developers will make necessary changes to the model and conduct full resolution "forecast only" experiments using ECMWF analysis or GFS v15.1 analysis over a long period (for instance, every 10th day for two years), and use GFS v15.1 configuration as the control.
- For bug fixes and addressing other "known" issues within GFS v15.1, developers will make necessary changes to the model and conduct full resolution "forecast only" experiments using GFS v15.1 analysis over a long period (for instance, every 10th day for two years), and use GFS v15.1 configuration as the control.
- Results from each of the experiments in the development phase will be evaluated against respective control experiments, and presented at the GFS v16 coordination meetings or other venues of opportunity.
- Model Evaluation Group (MEG) will provide necessary support for evaluating the development phase experiments, and the developers will make a proposal for inclusion of model changes into the Master.
- A configuration review committee consisting of EMC management, Project Manager, Project Leads, and Code Manager will evaluate the proposal and provide recommendations for acceptance (or rejection) of the science changes.
- If accepted, the developers will follow the code management procedures documented in Section 1.3.10 and commit the codes to the Master.

All changes needed for inclusion of approved scientific upgrades must be committed to the Master repositories before the integrated Configuration Test phase. Upgrade candidates not selected for inclusion or not ready before the next phase will be returned to the pool of potential upgrades for next version of GFS (or other applications as appropriate). There will be no exceptions for inclusion of new science changes after the development phase is completed.

3.1.2 System Integration and Configuration Test Phase

This phase pertains to integrating and testing all candidate upgrades for all components with a model configuration intended for implementation of GFS v16 into operations. This phase includes assembling all approved science changes, conducting tests for technical and scientific integrity and robustness, fine tuning of model parameters, addressing dependencies for pre- and post-processing tools and libraries, and conducting full resolution cycled experiments for one summer month and one winter month (and selected case studies recommended by MEG) and evaluated comparing with GFS v15.1 as control to confirm intended benefits from individual component testing in the development phase are retained. The same metrics used in the development phase described in section 4.1.1 will be used for evaluation in the configuration test phase.

If the results are not favorable to proceed with, developers of the respective upgrade components will work with the Project Manager to develop alternate strategies, which may result in re-tuning the model configuration and repeat the system integration tests as needed.

The configuration test will be performed on the NCEP WCOSS computers

At the end of this phase, the appropriate configuration is selected and frozen in preparation for the subsequent pre-implementation test phase. All necessary changes to the workflow, scripts, build system, production suite libraries, pre-and post-processing utilities, model evaluation tools, and process automation aspects will be finalized in this phase. A pre-implementation tag will be created for retrospective and real-time experiments.

3.1.3 Re-analysis and Reforecast

TBD

3.1.4 Pre-implementation Test Phase

GFS is the flagship model of NCEP for medium range weather forecast guidance, and influences a significant portion of the NCEP production suite through downstream and upstream dependencies. Apart from primary customers and stakeholders of the National Weather Service, GFS analysis and forecasts are used by the larger weather enterprise across the globe. Apart from real-time operational forecasts, retrospective experiments will provide valuable information for calibration and validation of statistical post-processing and dynamical downscaling applications. Documenting the model performance over a sufficiently long period of time will enable the weather enterprise to adapt to the characteristics of the model behavior and biases. Pre-implementation testing and evaluation with a frozen configuration of the GFS v16 modeling system intended for transition to operations is the most crucial phase of this project.

Typical pre-implementation test includes retrospective and real time experiments covering about a three year period, primarily to capture the seasonally varying hurricane conditions and large sample of severe weather events where the forecasts matter the most.

Increased complexity of the modeling system with cycled data assimilation, demand for more computational resources to accommodate expensive model upgrades, and severe constraints on the available resources on WCOSS and NOAA RDHPC, it is impractical to conduct continuously cycled experiments for the entire test period. It is imperative that the pre-implementation tests are divided into multiple streams and use all available resources for conducting, monitoring, trouble-shooting, and evaluating retrospective and real-time experiments in a rapid response mode. It is also important to keep in mind the data assimilation system requirements for providing consistent analysis. Usually it takes about 2 weeks of spin-up for generating model initial conditions that provide balanced model consistent analyses for each stream of experiments, which needs to be taken into account while dividing the test period into multiple chunks.

To maximize the throughput of pre-implementation tests, and to address the stakeholder requirements, the retrospective and real-time experimental setup for GFS v16 will be divided into the following streams:

- Stream 0: Real-time experiments (March 1, 2020 - implementation date)
- Stream 1: 2017 Hurricane Season (May 1, 2017 - November 10, 2017)
- Stream 2: 2018 Hurricane Season (May 1, 2018 - October 31, 2018)
- Stream 3: 2018/2019 Winter Season (December 1, 2018 - May 15, 2019)
- Stream 4: 2019 Hurricane Season (May 15, 2019 - November 30, 2019)
- Stream 5: 2019/2020 Winter Season (December 1, 2019 - February 29, 2020)

Detailed test plan will be developed prior to the start of the pre-implementation phase (link TBD)

The two last weeks of this phase is focused on summarizing all the evaluations and endorsements from the stakeholders. The EMC Configuration Change Board (CCB) meeting is conducted during this phase to review and assess the result from the proposed GFS configuration, the EMC director approval is granted during this meeting if the upgrade is deemed beneficial. The NCEP director approval is conducted subsequently.

The real-time tests will be performed on the NCEP WCOSS computers. Other streams can be run on WCOSS or RDHPC or potentially cloud computing (if available).

3.1.4.1 Accepting Mid-stream changes once pre-implementation T&E is commenced

Once the configuration for GFSv16 is finalized and codes are frozen, a pre-implementation tag will be created and used for real-time and retrospective experiments. In the event of any change required to be included in the pre-implementation configuration after the code freeze, the following guidelines will be used:

- **Code/Workflow changes that will not alter results:** For modifications that are non-answer changing, the code manager will make a decision to include them into the GFSv16 pre-implementation branch at an appropriate time determined by the project lead. These changes are generally required to improve the efficiency of the system or fix any issues with the workflow. There will be no impact on scientific evaluation aspects due to these changes.
- **Code/Workflow changes that will alter results:** Every effort will be made to not to make any changes that will impact the scientific integrity of GFSv16 pre-implementation package. Invariably, there will be discoveries from real-time and retrospective model evaluation that might reveal scientific issues negatively impacting model performance, and potential scientific changes may be required to address any degradation of results that could put the implementation at risk. Another situation is uncovering any bugs present in the pre-implementation tag that require fixing in a timely manner to make the system scientifically accurate and robust. The following guidelines will be used to make a decision when such situations arise:
  - An internal EMC Implementation Review Committee (EIRC) consisting of the management team (Deputy Director, three Branch Chiefs and three Group Chiefs) will be responsible for making decisions.
  - Project lead, in consultation with the model evaluation team and corresponding model developer, will make a proposal to the EIRC for either a science change or bug fix that will alter the results (thereby invalidate all experiments conducted till then), providing justification for such a change, and pros and cons for including the change.
  - EIRC will review the proposal and make recommendations to accept or reject or conditionally accept the change(s) based on the impact to schedule and resources. If it is early in the process, it may be advisable to restart the real-time and retrospective experiments. Output products and downstream related changes can be considered for acceptance as long as they don’t impact scientific outcome.
  - In case of a conflict, EIRC will consult with EMC Director for final resolution.

3.1.5 Verification and Validation

The EMC Verification, Post-Processing, and Production Generation Branch will play an important role in the assessment of the GFS v16 upgrade and will be responsible for coordination and summarizing the stakeholders’ evaluation during the pre-implementation test as described in the project plan. The Branch will assist with the EMC internal scientific evaluation, downstream products validation, post-processed products and data formats evaluation, and coordinating the NWS field evaluation. Additionally, the Branch will communicate model evaluation results to all stakeholders and model evaluation participants, through regularly scheduled briefings.

The V&V group at EMC has created a GEFS verification website that will contain all operational, parallel, and experimental verification static graphics for the GEFS, and can be accessed at: https://www.emc.ncep.noaa.gov/users/meg/gefs_verif/retros/. All metrics used in the prior evaluation of GEFS v11 will be used for GEFS v12 evaluation. In addition, the web-based tools for verification data visualization, METViewer and METExpress, can be used by EMC staff and collaborators to generate custom graphics plots using output from MET. The EMC V&V team will make available all GEFS v12 retrospective and parallel run data available via these web-based tools, so that both internal and external users can visualize specific metrics within custom temporal windows.

3.1.6 Field Evaluation

EMC's Model Evaluation Group (MEG) will coordinate the National Weather Service field evaluation of GEFS v12, working with NWS HQ, Regions, and National Centers to collect their evaluation information on GEFS v12 performance. The field evaluation is one of the last steps prior to briefing the NCEP Director for operational implementation approval, and will be conducted once the scientific component of the code is complete (i.e., "frozen" code) and all retrospective runs are complete. Results from the MEG evaluation, both internal and external, will be assessed and examined by the GEFS project manager, and any significant findings will be addressed by the modeling team prior to implementation.

The MEG will provide a comprehensive web page that links to all aspects of the model evaluation for GEFS v12. The GEFS v12 page can be found at: https://www.emc.ncep.noaa.gov/users/meg/gefsv12/.

Another major component of the GFS v16 field evaluation will include coordinating a test of GFS v16 output data with the GFS Model Output Statistics (GFSMOS), in a partnership with the Meteorological Development Laboratory (MDL). The test will determine if GFS v16 output degrades or alters, in a statistically significant way, the current GFSMOS output. If MDL concludes that GFSMOS needs to be redeveloped using GFS v16 data, then MDL will need to obtain two full years of GFS v16 retrospective data and re-develop the static equations that create GFSMOS, prior to implementation. A GFSMOS redevelopment effort could alter the implementation schedule significantly, due to the effort needed via MDL personnel to redevelop the GFSMOS equation suite, and additional work needed by NCO to implement a new GFSMOS version concurrently with GFS v16.

3.1.7 Downstream Model and Product Evaluation

As part of GFS v16 evaluation, all GEFS downstream products need to be evaluated by the downstream products developers prior to the CCB.

3.1.7.1 Evaluation and impact assessment from HWRF/HMON, GEFS, AQ and wave models

The NCEP Global Forecast System (GFS) analysis and forecasts provide initial and boundary conditions for the HWRF/HMON hurricane models and the GDAS/GFS EnKF ensemble forecasts provide initial perturbations for GEFS. It is critical that GFS upgrades do not inadvertently degrade the forecast performance of these important downstream applications. Special attention is given to these two applications (HWRF/HOMN and GEFS) by including a test plan that documents the impacts of GFS changes to them. Usually NHC provides a list of high priority storms for testing of HWRF/HMON with new GFS upgrades, and GEFS uses one summer and one winter period to test the impact of GFS upgrades. The same will be applied for GFSv16 downstream evaluation.

Since the wave model is being subsumed by GFSv16, there will not be a need for separate evaluation of Global Wave Modeling System.

Air Quality models also depend on native model output from GFS, and the EMC AQ team will conduct the testing required to demonstrate non-negative impacts of GFS upgrades to CMAQ model.

In addition, several downstream products generated from GFSv16 should be validated, see the references section for a comprehensive list of downstream products to be validated.

3.1.7.2 Evaluation of MDL MOS and NHC TC Genesis

In addition to the downstream models mentioned in Section 3.1.6.1, two additional applications will need to be extensively tested and evaluated. One of them is the Model Output Statistics (MOS) maintained by Meteorological Development Laboratory (MDL), which requires specific input data from large-scale retrospective runs with GFSv16 configuration. The workflow for retrospective experiments will include scripts for generating the data required for MOS evaluation. MDL is responsible for providing assessment of impact of GFSv16 data on MOS skills using a subset of data (one summer month and one winter month) and inform whether there is a need for collecting data from retrospectives for multiple seasons.

The National Hurricane Center (NHC) requires evaluating tropical cyclogenesis forecasts from multi-season retrospectives from GFSv16. EMC will provide a specific subset of model output consisting of variables needed for computing TC genesis parameters. NHC is responsible for doing the TC genesis evaluation and provide a report on the findings.

3.1.8 Transition to Operation

The transition to operations follows the Environment Equivalence standards (referred to as the EE2 process)[1]. A brief overview is provided here with details laid out in the EE2 documentation.

After experimental testing has reached an advanced enough stage, the first interaction with NCO on the project is established via the initial coordination Environmental Equivalence (EE) or "kickoff" meeting. It is expected that by the time of the EE meeting, development testing of the system should have reached an advanced enough stage for specific resource details to be known. For new systems an existing system upgrade that requires a >=3x increase in computing resources, approval must be obtained from the NCEP High Performance Computing Resource Allocation Committee (HPCRAC), which in EMC is coordinated through the Engineering and Implementation Branch head. The brief to HPCRAC should be done as early as possible but not later than the time of the EE Kickoff meeting with NCO.

Attending the EE kickoff meeting will be the project development team, NCO SPA team, Dataflow team and (if applicable) a member of the EMC Engineering and Implementation Branch[2] who has been assigned to the project team for EE2 compliance. In this meeting the developers present to NCO the following information:

1. A brief overview of the new project or the upgrades planned for an existing production system.
2. For new systems, the expected computing resources to be needed; for existing systems, the changes in resources needed compared to the current production system. The resource information provided should include:
    a. Node usage and expected run end-to-end time on the production machine
    b. Total disk space usage per day or per cycle required on the production machine
    c. Total disk space usage per day or per cycle on the operational NCEP FTP/NOMADS server
    d. Any changes to model products that are processed for distribution to customers (inc. AWIPS).
    e. Anticipated changes to output grids (either in GRIB2 or GEMPAK format).

The NCO team at the EE meeting will list all outstanding Bugzilla tickets for the modeling system, with the developers providing information on the extent to which the planned upgrade addresses these issues. All Bugzilla items need to be either addressed by developers by the time of the handoff of the system to NCO. All actions done by developers on Bugzilla tickets (either resolving them or reasons why they could not be addressed) must be documented in the online Bugzilla database. The development organization is encouraged to discuss code conformity issues with SPAs well in advance of the code

[1] https://docs.google.com/document/d/1zR6-MfLDluAoMNv7J35XO8DCfpkc3MwePHcAPOWJS04/edit?usp=sharing

[2] Note: this will only apply to the implementations that EMC is responsible for. Other DevOrg's will decide what their representation at this meeting will be.

hand-off date, including giving NCO an early look at the codes so the SPAs can comment on adherence to standards. On or around the time of the EE kickoff meeting, a Public Information Statement (PNS) that outlines the major changes being introduced in the implementation is written by the developers and sent to NWS Headquarters for dissemination per National Weather Service Instruction 10-102 for comments from stakeholders.

After the EE meeting, major development is ended and the final version is frozen for the science evaluation test of the system, which is run by the developers. Ideally this test should include both real-time and retrospective forecasts which are to be evaluated by stakeholders inside and outside of NWS. If multiple full season retrospectives are not possible due to resource constraints, stakeholders should be given every opportunity to request specific cases of interest to be rerun. Prior to the start of the science evaluation, the developers write a Request for Evaluation letter for distribution to stakeholders. The evaluation letter describes details of the system changes, what impact these changes should have on analysis / forecast performance. Those who agree to evaluation the package are then notified by the developers when the evaluation starts and ends. The length of the science evaluation period is at least 30 days, but may be considerably longer for major high-profile system upgrades (like the replacement of the NCEP Spectral Model with the FV3 model in the GFS).

Once the science test is completed and evaluations are collected, the Change Control Board (CCB) meeting for the project will be held, which is essentially a briefing on the project to the EMC management team. At this meeting the project PI will brief the EMC Director on the project with an emphasis on the scientific results and the system evaluation by stakeholders during the science test. If the EMC Director signs off on the project, the immediate next step is to give the Science briefing to the NCEP Director (referred to as the OD brief), during which the PI gives an overview of the planned changes, and the stakeholders discuss their evaluations. If the NCEP Director approves the planned science changes for implementation, the PI finalizes the Service Change Notice (SCN), submits to NCO along with code hand-off, and NCO sends it to NWS Headquarters for dissemination. At the CCB and NCEP Director Briefings, developers must get approval from the EMC and NCEP Directors for any changes in product delivery times. If during their IT testing (see next section) NCO determines that product delivery times are > 5 minutes from the current operational systems, NCEP Director approval is required for them to proceed with the implementation.

3.1.9 NCO IT Test Phase

Once the system is handed off to NCO, the SPA team will examine the package to see if it conforms to WCOSS Implementation Standards and fill out the implementation checklist. They will perform IT testing, the scope of which will vary based on the complexity of the system. The IT testing consists of checking the capabilities of the code, including capacity management, failure mode, restart, cold start, code stability and scalability, dependency checkout, bug verification, standards enforcement and output product technical verification. This IT testing will usually include both source code checks (warning messages during code compiles, arrays out-of-bounds, memory leaks) and the impact of missing upstream data on the system. After the IT testing NCO informs the developer of any issues found that should be addressed. If NCO deems the package acceptable it will proceed with setup of the parallel production system. If there are sufficient deficiencies in the system, NCO will send it back to the developer with instructions on what issues need to be addressed. During IT testing NCO determines whether product delivery times are within 5 minutes of the current operational version of the system. If delivery times are > 5 minutes later with the new version then the NCEP Director needs to be informed for approval for the implementation to proceed.

Once the package is fully compliant with NCO Implementation standards and is setup to run in its production configuration, NCO will run a 30-day stability test. If there are any problems during this 30-day test (system code failures, system bugs, issues with downstream products and downstream modeling systems) these problems are addressed by the developer or the SPA, and the 30-day test is restarted. If NCO determines that product delivery times will be > 5 minutes later than the current ops system then the NCEP Director needs to be informed for approval for the implementation to proceed.

After a successful 30-day stability test, NCO gives the Technical Briefing on the system to the NCEP Director, whose approval will allow the system to be implemented into operations about 1 week later.

3.2 Key Milestones and Deliverables

The key milestones and deliverables for typical Q2 implementation are listed in the table below, these are estimated dates and will be refined as needed and based on available resources (support staff and Computer/IT), readiness of the GSF components, and management direction. Timeline for GFS v16 is provided as example.

Milestone	Timeframe	v12	Notes
Complete initial testing and tuning		Q4FY18	Testing and tuning will include examination of results from a suite of case studies provided by the Model Evaluation Group. Any significant findings or errors will be addressed, and signed off by the GEFS v12 project

			manager, prior to selecting final configuration and creating retrospective simulations.
Select configuration and Start re-analysis & 35-day reforecast	1 year prior to implementation	Q4FY18	Secure HPC resources
Create a T2O quad chart	18 months prior to ops implementation	Q2FY19	Update this project plan for add details for the upcoming GEFS upgrade
Create a project plan and charter	18 months prior to ops implementation	Q3FY19	
Select final GEFS v12 configuration and start pre-implementation test	9 months prior to ops implementation	Q3FY19	Includes retrospectives for atmosphere, wave, and aerosol, and real time for wave and aerosol,
Initial coordination with NCO (EE)	1 year prior to ops implementation	Q4FY19	Secure pre-implementation resources and potential operational resources
Submit the Public Notice Service (PNS)		Q2FY20	Should include products retirement plan
Complete pre-implementation test	2 weeks prior to code handover to NCO	Q3FY20	
Complete EMC & stakeholders evaluation	1 week prior to CCB and OD brief	Q3FY20	All retrospective simulations and reforecasts are to be completed prior to start of NWS field evaluation.
EMC CCB	19 weeks prior to ops implementation	Q3FY20	
NCEP Office of Director (OD) brief	19 weeks prior to ops implementation	Q3FY20	
Deliver full code to NCO	18 weeks prior to ops implementation	Q3FY20	This includes GEFS and all downstream codes
Submit Service Change Notice (SCN)	6 weeks prior to ops implementation		EMC to generate and submit the SCN to NWS HQ
Start IT test	5 weeks prior to ops implementation		
Implementation	Day “0”	Q4FY20	

3.3 Project Assumptions and Risks

Assumptions and risks associated with the GEFS v12 development and transition to operations are summarized below:

- Scientific assumptions and risks

The key assumption for this project is that the planned scientific upgrades for GEFS does not degrade the scientific performance of the model. In particular the planned upgrades to the stochastic physics, resolution, increased number of members, and coupling with the wave and aerosol, all need to show no degradation to current operational model (GEFS v11) for the primary metrics identified in Section 2.3. In addition, field evaluation & concurrence and approval from the NCEP director are required to transition the model into operation, without that, the model will not be upgraded.

- Technical assumptions and risks

Technical performance (CPU, I/O footprint,…etc.) of the model is crucial to the operational implementation of the GEFS v12; unsatisfactory technical performance will require additional code optimization and may lead to delay in transitioning GEFS upgrades to operation.

- Resources

Personnel and compute resource needs listed in tables 8.1 and 8.2 are critical to the success of this project; inadequate resources may lead to reducing the scope of this upgrade and/or delaying the operational implementation of the GEFS v12.

3.4 Collaboration – Organization Interactions

As part of the UFS community, EMC GFS team collaborates and coordinates the development activities with most of the SIP working groups to effectively transition new innovations to the GFS components and transition the GFS application to operations. In particular, collaborations with the following SIP working groups is essential:

- **Infrastructure and System Architecture SIP WGs**: The strategies for NEMS infrastructure development, code management, workflow and system libraries and utilities are described in the project plan (SIP Annex 2 and Annex 3)
- **Coupled System teams**: Development of coupling to WAVEWATCH III is coordinated through Coupled System development team as described in the project plan (SIP annex 2 and Annex 8)
- **EMC Model Evaluation Group**: (MEG website)
- **Downstream products developers:** Coordination with all the GEFS downstream product developers is vital to ensure that the GEFS upgrades do not affect the GFS downstream products negatively, the list of the anticipated downstream products for GEFS v12 can be found in the references section .

4. Roles and Responsibilities

Role	Name	Responsibilities

Project Sponsor	Brian Gross	Provides the budget and funding, and sets the strategic goals and objectives.
Project Manager	Vijay Tallapragada	Responsible for the overall success of the project, including project team, milestones and deliverables.
Project Manager Support	Farida Adimi	Provides support to the project manager and project area leads; ensures all components are integrated and coordinated with each other.
Project Area	Lead	Responsibilities
Project Leads	Yuejian Zhu Dingchen Hou	Responsible for coordinating activities related to all components and integrating them into the GFS framework.
Code Managers	Dingchen Hou (GEFS) ?? (WAVE) ?? Aerosol Kate Friedman (Workflow)	Responsible for the overall success of the project area including providing status reports, issues, concerns, and risks to the project lead and project manager. The project area lead is also responsible for meeting all milestones and deliverables associated with their projects.
Verification tools	Binbin Zhou (Atmosphere) Deanna Spindler (Wave) Partha Bhattacharjee (Aerosol) CPC/??? (Atm probabilistic)	
Atmosphere		
Wave	Henrique Alves	
Aerosol	Jeff MacQueen	
Wave-Atm coupling	Jessica Meixner	
Verification & validation	Alicia Bentley (verification webpages)	
Field evaluation	Geoff Manikin	
Documentation	Valbona Kunkel	
Post Processing & Products	Huiya Chuang	
Pre Processing/Obs	Shelley Melchoir	
Code Optimization	Dingchen Hou (GEFS) Walter Kolczynski (Atm-Wave coupling) ??? (Aerosol)	Need additional support from IBM specialists
T2O and EE2 compliance	Lin Gan & Hang Lei	
Transition to Operations	NCO/Steven Earle	

5. Resources

5.1 Support staff

Role	Number of FTEs	duration from	to
Management	0.2		Implementation
Management Support	0.3		through code delivery
Stochastic physics development (PSD)	????		
Tuning and configurations	3		through code freeze
Re-analysis (PSD)	0.5		through code freeze
Reforecast	0.5		
Integration (technical)	1	present	Implementation
Pre-implementation testing	2	present	
Wave model development I&T	1.5	present	through code delivery
Aerosol model development (EMC+GSD)	1+1???		through code delivery
Post processing & products	2	present	Implementation
Statistical post processing			
Verification tools	3	present	Implementation
Field evaluation (MEG)	2	when retrospective runs are finished	Implementation
Workflow development, monitoring of retro and real-time parallels	4	present	Implementation
Code management (GEFS, Wave, Aerosol, and Workflow)	4	present	Implementation
T2O/NCO Coordination/EE2	1	freeze code/workflow	through code delivery
Total			

5.2 Compute and IT

The estimated pre-implementation IT Resources needed for each implementation is shown in the table below. Note more core hours may be required to rerun some of the streams in case major issues are uncovered during pre-implementation test.

Configuration (High-res/Ensemble)	Parallel Streams	Period of Testing	Platform and Computing Nodes	Core Hours (million)	Online ptmp disk (TB)	HPSS storage (TB) per cycle

6.0 Appendices

5.3 6.1 Global Ensemble Forecast System Components

5.3.1 Global Forecast System/Global Data Assimilation System (GFS/GDAS)

Need description and link to the GFS project plan and charter

5.3.2 Stochastic Physics

To be aligned with NOAA's mission of generating a unified coupled forecast system to cover the time scale from weather to seasonal, GEFS has carried out investigations on the strategy to potentially improve the forecast skill on weather, week-2, week 3&4 time range (sub-seasonal time-scale), and further to cover monthly forecast. A recent investigation is testing the impact of different stochastic perturbation schemes that represent the model uncertainty on the performance of ensemble forecast (Zhu et al. 2017; Zhu et al. 2018; Li et al. 2018)). The motivation for this work came from the concerns of the under-dispersion (or overconfidence) of the current operational version of GEFS (GEFS v11 with EnKF initial perturbation + STTP (Stochastic Total Tendency Perturbation)) on medium range forecast especially over the tropics (Hou et al, 2008, Zhou et al. 2016, 2017).

Although STTP scheme compensates the less error growth from initial perturbations to some degree, the impact of the STTP is mainly over extra-tropics during boreal winter season with less impact on the spread over tropical region. It is well known that MJO is a major source of the predictability on sub-seasonal time scale. Therefore, to improve the representation of the model uncertainty over tropics is a possible pathway to potentially improve this source of sub-seasonal predictability. A suite of three widely accepted stochastic perturbation methods (SPs hereafter) are thus applied to GEFS to represent the model uncertainties instead of STTP more efficiently (Table 1, second row). The scheme of SPs are SKEB from expectation of making up sub-scale energy lost due to imperfect computation algorithms;

SPPT with five different spatial and temporal scales (Fig. 2); and 3) Stochastic Perturbed Humidity (SHUM; Tompkins and Berner, 2008) with single spatial-temporal scale, and near model surface layers. These schemes have already been implemented in the National Center Environmental Prediction (NCEP) Global Forecast System (GFS) model for use in the hybrid-EnKF data assimilation system, then basically available for use in the GEFS for testing and modification. A detailed description of these schemes are as following.

The SKEB scheme has been used to represent dynamical uncertainty through subgrid-scale processes that propagate upscale. A stream function forcing from the total dissipation has been applied to SKEB. Depends on numerical model design, the numerical dissipation (i.e. the diffusions) is only part to be considered in current GFS version. The generations of such perturbations on each vertical level are independently to provide some vertical coherence through vertical smoothing. Overall, the SKEB scheme should improve the global power spectrum and increase forecast spread.

The SPPT scheme perturbs the total tendencies of temperature, wind, and water vapor during numerical integration generated by the GFS physics parameterizations (after all physics processes). Current version of SPPT implies five different random patterns with different time scale and correlation length scales to generate the tendency perturbations. The patterns, in general, are uniform in the vertical, except their magnitude of amplitude are reduced and taped to zero gradually for both near surface and above the tropopause. The maximum amplitude of five scales are 0.8, 0.4, 0.2, 0.08 and 0.04 respectively. Fig. 2 demonstrates the individual independent random scale patterns and combined 5-scale random pattern.

Need description for the Stochastic Physics?

1.3.3 Reforecast/Re-analysis

One of the ways to improve numerical weather predictions is through statistical post-processing, i.e., the process of adjusting the current forecast guidance using past forecasts and observations/analyses from the same or very similar analysis/prediction system. Past forecasts can be generated through the production of reanalyses (for model initialization) and then reforecasts. Reanalyses are retrospective gridded analyses of past weather states, generated with the same models and assimilation methods used operationally. Reforecasts here refer to the retrospective weather forecasts, again generated with the same or very similar modeling systems. The 20 years reanalysis (1999-2018) and 30 years reforecasts (1989-2018) have been designed to support GEFSv12 implementation which is scheduled for Q4FY2020

Reanalysis:

20 years (1999-2018) reanalysis has been planned, led by PSD/ESRL, designed as 5 streams parallelly in order to finish during available time window (5 years for each stream with 1 year system spin up).

Reanalysis has used the latest FV3 GFS model version, with C384 (approximate 25km horizontal resolution) and 64 hybrid vertical levels for GSI, and hybrid with 80 EnKF (C128-approximate 75km horizontal resolution) members, which includes SPPT and SHUM stochastic processes.

Reanalysis has introduced IAU (Incremental Analysis Update) process, which the analysis increments get added to the model state over a period of time (each hour over 6 hours time window)

Reanalysis used NOAA R&D HPC resources to process 20 years reanalysis, stored analysis and restart forecast on NOAA HPSS.

Generate FV3-GEFS "restart" from end of IAU window (00UTC+3) in order to generate consistent forecast products from future operations.

Generate similar analysis and 1st 6hr forecasts for 20 years reanalysis

Reforecasts:

30 years (1989-2018) reforecast has been planned, led by EMC/NCEP, designed as 5 members, out to 16 days for each 00UTC initialized, except for every Wednesday to run 11 members, out to 35 days.

Reforecast has used the same model version as future GEFSv12 implementation, with C384 (approximately 25 horizontal resolution) and 64 hybrid vertical levels.

The CFS reanalysis and ETR-BV perturbations has been used to initialize first 11 years (1989-1999).

FV3 based reanalysis include EnKF and IAU) will provide 3-hour restarted analysis and perturbations for rest 19 years reforeast integrations.

All 30 years reforecasts at 0.25d (0-10 days) and 0.5d (10-35 days) will be saved on NOAA HPSS for 5 years in order to support stakeholders and community research.

Selected variables (22 2D variables - surface; 55 3D variables - upper air) will be saved on WCOSS disk storage to allow stakeholders, such as CPC, WMC and MDL to access easily.

All computations are applied on WCOSS development machine, and consider to speed up this process by applying cloud computations.

Need description of this component; maybe moved to other sections

5.3.3 Interoperable Physics Driver (IPD) and Common Community Physics Package (CCPP)

The Interoperable Physics Driver (IPD) is a software infrastructure developed to facilitate the research, development, and transition to operations of innovations in atmospheric physical parameterizations. The IPD enables coupling the FV3 dynamic core and GFS physics suite with a modular infrastructure that is computationally efficient and easy to implement new physical parameterization schemes or physics suites. Details of the latest version of IPD v4 are documented here.

More recently, NGGPS has initiated development of the Common Community Physics Package (CCPP), which is designed to facilitate the implementation of physics innovations in state-of-the-art atmospheric models, the use of various models to develop physics, and the acceleration of transition of physics innovations to operational NOAA models. The CCPP consists of two separate software packages, the pool of CCPP-compliant physics schemes (CCPP-Physics) and the framework that connects the physics schemes with a host model (CCPP-Framework). At the time of writing this document, CCPP is not accepted yet for operational considerations. Implementation of CCPP into operations depend on successful acceptance of CCPP and integration of advanced physics options selected for GFS v16. More details on CCPP can be found at the GMTB site.

5.3.4 Write Grid Component

The output and IO related downstream processes are implemented into NEMS framework as a write grid component that releases forecast tasks from IO tasks, and to process forecast data and to write out results. The output data are represented as ESMF fields with meta data and data values, these fields are stored in forecast grid component export state. ESMF regridding is used to transfer the data from forecast grid component to write grid component on a desired grid in various data formats including nemsio and netcdf. Downstream jobs such as post-processing and verification can be conducted on write grid component where all the output data are available. More details are at: https://vlab.ncep.noaa.gov/group/fv3gfs/ or https://vlab.ncep.noaa.gov/web/fv3gfs

5.3.5 Coupled System Components (Land Surface, Ocean, Sea-Ice, Waves, Aerosols & Chemistry)

Current operational GEFS is still uncoupled to other earth system components such as ocean, sea-ice, waves, aerosols, and chemistry. Land surface processes are considered part of the physics package along with near surface sea temperatures (NSST) providing oceanic boundary conditions. The future goals of NPS is to move towards coupled modeling using UFS infrastructure. These component models are developed in a community modeling framework and will be included in future GEFS upgrades as they become mature and ready for transition to operations. As such, description of these components in the project will be limited to the ones that will be considered for operational implementation (e.g., wave ensemble and model aerosol/chemistry for GEFS v12). Details on UFS components are published at the UFS portal.

5.3.6 Unified Post Processing, Product Generation, Tropical Cyclone Tracking, Aviation Products etc.

The GFS utilizes NCEP's Unified Post Processor (UPP) system to generate forecast products in the required Grib2 format for dissemination. Using a common post processor for all NCEP weather models allows NCEP to compare and verify all model output fairly. GFS post processing system continues to add new variables with each GFS upgrades. These new variables include simulated satellite imagery, radar reflectivity, global aviation products etc., along with bufr sounding data. A separate tropical cyclone tracker is used to produce ATCF formatted tropical cyclone track, intensity, structure, and phase information. Similarly, an extra tropical tracking software is employed to generate information on non-tropical systems. GFS started to distribute higher resolution 0.25 degree data to users with its 2015 upgrade. GFS began distributing hourly 0.25 degree data up to F120 in May 2016.

In addition to model forecast output on regular lat-lon projection in Grib2 format, several downstream products are generated using the post-processed output to cater to various users and stakeholders. A detailed list of all products generated by GFS in operations is available at: https://www.nco.ncep.noaa.gov/pmb/products/gfs/

5.3.7 Verification, Validation, Visualization and Model Diagnostics

Verification, validation and diagnostics are critical for supporting model development efforts and generating objective evidence for demonstrating model improvements during the upgrade cycles. A comprehensive Verification System Data Base (VSDB) developed at EMC is currently used for generating statistical verification metrics to support model evaluation efforts. Various standard verification metrics comparing model output with analysis, observations, and climatology are developed and used for both real-time and retrospective experiments. In addition, several tools including grid-to-grid verification, gird-to-obs surface verification, upper-air fit-to-observations, station-based precipitation verification, and a detailed "scorecard" showing statistical significance of model differences are used for model evaluation. Routine evaluation of global models from various global operational centers are also managed by VSDB. More details on VSDB and its functionality are documented at: https://www.emc.ncep.noaa.gov/gmb/STATS_vsdb/

The EMC and the UFS community have chosen to use the community based Model Evaluation Tools (MET) developed at NCAR, and EMC is in the process of transitioning all V&V software to use MET. Transition of VSDB to MET for global ensemble model verification is expected to happen in summer 2019, ready for use in the GEFS v12 evaluation. Verification tools have not yet been incorporated into any GEFS model development workflow, and are not planned for GEFS v12, but are tentatively planned for GEFS v13. More information on MET, METplus+, and associated functionality are documented at: https://ral.ucar.edu/solutions/products/model-evaluation-tools-met

In addition to objective evaluation of model performance, several diagnostic capabilities along with visualization tools are developed to support subjective evaluation of selected case studies recommended by the field (usually associated with high impact weather events). These efforts are managed by the Model Evaluation Group (MEG) of EMC's Verification, Post-Processing, and Product Generation Branch. MEG coordinates all evaluation aspects of the model upgrades. A web page for the GEFS v12 evaluation has been developed and can be accessed at: https://www.emc.ncep.noaa.gov/users/meg/gefsv12/.

Need V&V description

5.3.8 Workflow, NCEP Libraries, Utilities, System Engineering and Code Management

Robust software infrastructure is required for supporting system architecture design and execution of complex modeling systems for research and operations. It is equally important to have reliable and reproducible workflow components with sophisticated exception handling for building and porting the codes to various HPC architectures. These include various software libraries, tools for system integration, configuration management, code repository management, and flexibility to operate in multiple environments. A robust global_workflow was developed and implemented for use with GFS v15.1 upgrade using rocoto workflow manager for research and development, and ecFlow for operations.

The system is designed based on principles that will allow the requirements and constraints to be met; minimize risks and impacts of the assumptions; and advance NCEP in the direction of the key drivers. A set of shared scientific libraries (NCEP Libraries) are developed to provide support of NCEP models development, management, and operations. Additional community based libraries include ESMF, CRTM, NUOPC Mediator, NetCDF etc.

Robust code management is another crucial element of system integration. Currently, all GFS codes are managed using Git, Gerrit and redmine based collaboration and development services offered by NOAA's VLab. VLab facilities are also used to support general project management aspects including issue tracking, risk management, and inter-dependencies of tasks. The following code management procedure is used for making changes to the GFS codes:

- Proposal of changes, including expected code and science impacts submitted by the developer through ticket system
- Evidence-based review of science impacts before final code review
- Review committee evaluates proposal and provides feedback
- If okayed, branch is created and software work completed
- Run regression tests in the branch to evaluate impacts on science and computational performance
- Master branch development merged into the branch, submit for code review
- Code review done by review committee and code manager
- Code is committed to repository

More details on access to the codes and code management procedure (including rigorous regression tests) are available at: https://vlab.ncep.noaa.gov/redmine/projects/nemsfv3gfs/wiki

A more robust code management and repository plan is being developed for community based UFS development efforts on Github.com. Until that becomes available, GFS v15.1 and GFS v16 implementations will continue using VLab Git for code management. Three categories of branches will be made available in github:

1. pre-dev (light testing, fast commit, broad options, serving community),
2. dev (tested for all the FV3 related applications, only contains options having potential for implementation),
3. master (implementation branches, FV3GFS, SAR, HAFS, etc. relatively fixed configuration, tested through parallel runs, targeted for implementation)

1.1 6.2 Project Status and Reporting

Project status will be reported to the EMC director at least on a quarterly basis during the EMC Project Management Review (PMR). Development progress related to all GFS components will be presented during the GFS weekly technical meetings (link). Regular coordination meetings to monitor and coordinate all activities related to GFV v16 development and transition to operations will start about two years priorior to operational implementation (link)

In addition, all activities related GFS v16 are tracked in the EMC PM projects through Vlab redmine (link).

1.2 6.3 References

Development and iImplementation plans

- The UFS Strategic Implementation plan (link)
- GFS v16 project plan and charter; this document (link)
- The physics plans (GFS v16 suite selection report, Independent panel report for GFS physics, GFS v16 supplementary test plan, GMTB)
- Data Assimilation plan for GFS v16 (link)
- Data Assimilation Observations plan (link)
- Verification and Validation plan for GFS v16 (link)
- Wave modeling plan (link)
- GFS v16 forecast timing test (link)
- GFS v16 DA timing test (link)
- Unified FV3-base weather and climate at GFDL (link)
- NPS GFS v16 downstream dependencies (link)
- The METViewer web site can be accessed at: https://metviewer.nws.noaa.gov/metviewer, and METExpress can be accessed at: https://metexpress.nws.noaa.gov/

EMC Quad charts

- GFS v16 T2O quad chart (link)
- FV3 Global development quad (link)
- DA development quad (DA Infrastructure, DA Observations)
- Physics development quad (link)
- Infrastructure development quad (link)
- Couple system development quad (link)
- Wave modeling development quad (link)
- Post Processing and Products development quad (link)

- Model evaluation quad (link)
- Verification quad (link)
- ObsProcessing quad (link)
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More details about the tasks and activities can be found in Vlab Redmine EMC projects (restricted to EMC members only)

- EMC projects (link)

STI AOP Milestones related to GFS development and implementation:

- Q1FY20: Integrate METplus into GFS workflow for internal GFS v16 testing and development
- Q4FY20: Update WAFS icing and turbulence algorithms to work with GFS V16
- Q4FY20: Complete development, testing and evaluation of GFS v16

1.3 Acronyms

List of related acronyms can be found here