Team Co-Leads: Dr. Shrinivas Moorthi (NCEP/EMC)/Dr. Jim Doyle (NRL Monterey)

Physical Parameterization Development

1.1 State of the Science

State of the Science:

Physical parameterizations (PPs) describe the grid-scale changes in forecast variables due to sub-grid scale diabatic processes. PP development has always been an intrinsic and critical part of continued global model improvement, and the result has been increased forecast accuracy, as more processes are accounted for and with increased sophistication appropriate for the model resolution and vertical domain. Since the diversity of diabatic effects on a global scale is extremely demanding, careful adherence to scientific principles and diagnosis must be part of any future development. Moreover, the interactions between various PPs play a major role in system forecast performance.

The operational NCEP Global Spectral Model (GSM) has a strong suite of PPs, comparable in accuracy and sophistication to those in any of the international models, but is nevertheless not optimal in some potentially important areas. These areas for potential improvement are discussed briefly below.

1. "Scale-aware" convective and boundary layer formulations
   At horizontal resolutions of 20 km or coarser, the typical assumption that penetrative clouds occupy a small fraction of the horizontal grid is of acceptable accuracy. However, current and future versions of the GSM will be at 13 km or finer, where this assumption leads to unacceptable biases in model performance. The classic heating and moistening profiles (e.g. moist static energy) due to penetrative clouds are forced by scale-dependent processes and do not converge; therefore, knowing the cloud fractional area in a grid box is critical to this PP (see Appendix 1). This is often called the "grey-zone" problem.

   Boundary layer (non-penetrative) clouds have been a long-standing shortfall in the GFS. Stratus decks, commonly off the west coast of North and South America, have not been well captured in the GFS. This weakness impacts sea surface temperature (SST) prediction in coupled systems and should be a major focus of the next-generation system. Vertically sub-grid clouds have not received as much attention as horizontally sub-grid clouds; increased effort could improve non-penetrative cloud PP.

2. Microphysics sophistication (replace Single Moment by Two Moment scheme)

Weaknesses in both penetrative and non-penetrative cloud PP impact the model radiative budget. The GSM total cloudiness is deficient by about 20% and both the Long- and Short-Wave forcings are 10-20% too small in the global mean when measured against CERES2 data. Some of these errors could be mitigated by increased sophistication in cloud microphysical properties, in particular concerning ice and stratiform clouds, ice supersaturation, ice habit and other important items.

3. Interactions between all physical processes (e.g. radiation, clouds, microphysics and aerosols)
   The GSM PP code structure, like many global models, has a highly modular structure that makes it easier to tune and/or replace with more modern formulations. Increasingly, however, it has been considered advantageous to treat moist convection as a unified entity, irrespective of whether it occurs as penetrative or boundary layer convection, whether it is sub-grid or grid-scale, and whether it is precipitating or non-precipitating. Some consideration of an improved PP code structure and a more unified PP treatment across all types of clouds may be useful.

4. Physically-based framework for stochastics in ensemble prediction
   Establishing a physically-based framework for stochastics in physical parameterizations
   In common with most international model PPs, the GSM does not have a well-designed accounting for sub-grid variability, stochastic processes and uncertainty estimates resulting from stochastic processes and model error. These considerations are thought to be important in the construction of ensemble-based forecast systems. Lack of sub-grid variability is most likely the result of PP development that has focused heavily on providing grid-point mean values to the forecast model. While variability on the highest resolvable (2-3 grid point) scales is unlikely to result in major changes due to dominant grid-scale smoothing at the smallest spatial scales, some advances in this area would be beneficial to reducing the amount of arbitrary and mechanistically-tunable nature of current stochastic schemes.

5. Hierarchical code structures
   The PPs should be designed for prediction on a wide range of temporal and spatial scales: climate to hourly weather, and 1-100 km grids. For each application, the effects of all physical processes that **could** be impactful need to be included. For multiple applications covering the full range of operational scales, this means that some non-impacting processes could be added to a monolithic code. One possible approach is to have a hierarchical PP code that contains an overall, well-connected framework of basic PPs with an increasing level of complexity that can be added or omitted depending on the specific application. One example is Single Moment and Two-Moment microphysics schemes.

1.2 Objectives

The overall objective for PP development is to transition (from research to NWS operations, R2O) improved (more complete, accurate and efficient) representations of atmospheric physical processes and their mutual interactions spanning a wide range of spatial scales from ~1 km to ~100 km, while continuing the current operational development activities. Continuing the current development path is necessary to keep the operational system competitive and to raise the performance bar for all new development work.

1.3 Strategy

The following are critical elements to the R2O strategy.

- Community involvement
  NGGPS will fund proposals from the research community (academia and Government Labs) as well as infrastructure within the NWS to coordinate, support, augment and implement proposed work, given that results demonstrate the candidate software's forecast value and HPC affordability in pre-operational tests. It is strongly recommended that Climate Process Team work be included in this NGGPS development, along with other projects and programs that address PP improvement.

- Evaluations
  Evaluations of developed PPs versus operational codes will be conducted in a transparent manner with well-defined, quantitative metrics (scores) or model "benchmarks" (minimal levels of performance) that a given PP must pass in order to be included in further testing with other appropriate combinations of PPs (with additional relevant metrics and benchmarks), and ultimately in fully-coupled models. Some metrics or benchmarks will be the same as for operations and more can be added through NGGPS-sponsored development and other community involvement. As the project matures, subjective evaluations from forecasters and exposure to the EMC Model Evaluation Group will be important. It is expected that this project will be close to maturity when the quantitative global scores from the new physics suite are very close to the operational scores, including such sensitive metrics as hurricane track and precipitation performance.

- NGGPS Scientifically-based Working Groups (SWGs)
  NGGPS development work will be organized into SWGs addressing highly related physical processes. Each SWG will manage code for its own specialized area, but coordination among the groups will be critical for efficient overall development since changes made in one group could impact all other groups. At a minimum, each NGGPS

SWG will need to coordinate with others addressing relevant physical interactions. E.g., a SWG working on microphysics must collaborate with the one doing radiation development to ensure development requirements and physical interactions are mutually considered. Principal Investigators (PIs) with accepted proposals will be assigned to the most relevant SWG and all PIs will coordinate their contributions, taking into account their proposed work and how it can achieve the SWG's objective(s).

The number of SWG infrastructure personnel needs to be determined from careful consideration of the work load that each SWG will require to carry out its function, including cross-SWG coordination and coordination with interested interagency groups. Each SWG will work with the Test and Evaluation Group (TEG) to plan and execute experiments and apply appropriate, standard diagnostics and verification. Experiments will be conducted using standardized verification and diagnostic tools maintained by the Global Model Test Bed (GMTB) and assembled in coordination with the Physics TEG and the NGGPS Verification Team. In addition, there will be a Parameterization Coordination Group (PCG) that will ensure close and efficient and effective technical working relationships across the SWGs, the TEG, and GMTB. Further details on the PCG are given in Section 5.2.5 below.

- Parallel development
  Each SWG will begin with the existing version of the operational global model. Code development will result in a new version with new physics contributed by one or more SWGs. Testing the new version will be through standard R2O procedures. Code development in the SWGs should be transparent across all groups, where code structures are synchronized periodically, so that the number of required changes is reduced to a manageable level; otherwise, code coordination becomes extremely unwieldy. While this is an additional burden on the SWGs, it will facilitate future operational transitions and reduce the overall transition effort. Code management strategies will be closely coordinated with the two related NGGPS teams: Overarching System Team and Software Architecture and Engineering Team (SAET).

- Development strategy
  In general, two strategies should be considered.
    o The first focuses on developing a single process upgrade (e.g., deep convection parameterization) and tuning it and the remaining physical processes to improve model accuracy.
    o The second strategy combines one or more closely allied processes and treats them as an entity to be tested together and the remainder of the physics. Tuning is still involved but the allied processes can be optimized as a unit, potentially

making fewer changes to the remaining processes and fewer changes to the entire PP code.

Subsequent testing combines yet other processes in an increasing hierarchy of PP combinations (with associated metrics and benchmarks), culminating in a fully-coupled model parallel to operations.

The best strategy for the huge NGGPS project is unclear, so that discussion with key developers is needed.

- Enhanced diagnostics

  Due to the complexity of this project, with many (if not all) aspects of the operational PP suite being modified, the role of diagnostics will be increasingly important for examining and interpreting model performance. There are many aspects of PP performance that are not currently captured with quantitative scores but should be considered in order to generate a more complete picture of model performance. Several examples are:
    o Diagnostics relevant to data assimilation, including differences between the model background and both observations and analysis
    o Diagnostics focused on sensible weather and surface observations
    o Enhanced availability and tools to utilize heretofore unused observation data sets
    o Neighborhood verification techniques considered in a probabilistic framework

  An enhanced set of diagnostics, and excellent interpretation leading to continual improvement, should be possible considering the influx of new scientific talent brought into the NGGPS project.

- Test and Evaluation Group (TEG)

  It is critical that testing and evaluation performed by each SWG be as uniform as possible. Therefore, infrastructure functions, as listed in Appendix 3, will be supported by GMTB to provide experiment design, a uniform scripting "test harness," verification data sets and offline component simulators to enable in-depth investigation of PP codes. The tools housed at GMTB will be developed and contributed by members of the SWGs, members of other NGGPS teams (such as Verification), the NGGPS PIs, and GMTB staff.

  "Testbeds" for each SWG, or combination of SWGs where multiple PPs are being tested, should be maintained by the Global Model Test Bed (GMTB) to allow relevant physics to be tested. Such testbeds would have the relevant driving and validation data sets to fully test the hierarchy of PPs (individual, to interacting PPs, to limited-area processes –e.g. convection, to larger regional then global scales). Driving data may be in the form of actual observational data sets, model output, or synthetic data sets to test the basic

performance of a PP over a wide range of idealized environmental conditions in order to "stress test" PPs.

There will be a hierarchy of tests for evaluating changes or replacements of PPs. Initial evaluation, using one or more case studies, will be performed by the SWG members. Once merit is demonstrated according to pre-determined metrics, GMTB staff will conduct comprehensive testing spanning a variety of meteorological conditions and seasons. If results demonstrate value, EMC consider the innovation for potential operational implementation and conduct pre-implementation testing.

All testbed codes and dataset management will abide by the NGGPS software development guidelines set forth by the NGGPS Overarching System Team and Software Architecture and Engineering Team, in close coordination with EMC. To ensure the TEG activities are compatible with NOAA operational (Transition to Operations, T2O) standards, the TEG will be chaired by an EMC representative.

1.4 Development Areas and Working Groups

It is recommended that a SWG be established for each major development area. The proposed development areas and SWGs are listed below. While the initial membership of a particular SWG may be small to begin with, having a group discipline allows for increased membership and better communication than otherwise.

1. Convection and Boundary Layer
2. Cloud Microphysics
3. Radiation
4. Gravity Wave and Large-scale Orographic (and non-Orographic) Drag
5. Earth System Surface Fluxes and State

The SWGs cover the basic PP areas and are listed in decreasing priority order in Appendix 2. Suggested, specific development work is also listed for each SWG. It is important that each SWG activity be shared and coordinated closely across EMC.

1.5 Parameterization Coordination Group (PCG)

The 6 SWGs and the TEG cannot operate independently, so there needs to be a management and coordination group to ensure that the totality of NGGPS PP development activities and resources is operating efficiently and effectively. The PCG will be chaired by the EMC Director and be comprised of all SWG representatives and the TEG Chair. The PCG Chair will report to NGGPS management on PP projects status and issues. In addition, critical SWG members may also be invited to serve on the PCG.

1.6 Short Term Priorities

In the shorter term, a number of priorities have been identified.

- Development and maintenance of a single column model that contains the baseline GFS physics, as well as developmental physics suites. The single column model should make use of the NUOPC Physics Interoperability driver. Well-established datasets for boundary layer, convection (shallow and deep) test cases need to be included as well.
- Evaluate the current GFS physics suite with an increased vertical resolution (~120 layers) and a higher model top (~100 km) in GFS. Identify key parameterizations that need to be advanced in order to achieve greater skill than the current operational vertical resolution.
- Unified convection parameterization that provides a scale aware capability.
- Advanced microphysics parameterization that has a double moment capability for some species and may be readily coupled with aerosol physics.
- Boundary layer parameterization improvements that are coupled with turbulence, clouds, shallow convection, and radiation. Approaches include the Simplified Higher-Order Closure (SHOC) and moist version of the Eddy Diffusivity-Mass Flux (EDMF) approach.
- Improved parameterizations to represent stationary and non-stationary orographic and non-orographic gravity wave drag to improve model representation of momentum fluxes, momentum budget and numerous phenomena such as the Quasi-Biennial Oscillation (QBO).
- Advance the parameterization of the land surface to address systematic biases and errors in short and medium range forecasts and to improve the representation of the diurnal cycle.
- Represent the interactions between various physical parameterizations as complete and realistic as necessary to improve the overall integrity of the physics suite and forecast skill.

1.7 Milestones, Resource Requirements, and Outcomes for Near-Term Objectives

To develop, integrate, test and document an optimum physics package, various projects need to be defined to meet both short-term (< 6 months) and long-term (6-60 months) goals. The projects are aligned with the SWGs and will be supported by NGGPS resources necessary to allow them to function optimally.

1.7.1 Short Term Projects to Meet Short-Term Goals

Short-term project information is tabulated below. Further details are in Appendix 4.

1. Conduct a physical parameterization workshop.

Lead scientist(s)	Project Name	Project Description	Collaborators	Resources
J. Doyle & R. Pincus	NGGPS Physics Workshop	Convene international workshop to discuss focus areas for formulation of a 5-year technical plan	Invited community members	Travel support provided

2. **Deliver interoperable driver and software framework for testing the evolving GFS physics suite and NGGPS Level 2 requirements.**

Lead scientist(s)	Project Name	Project Description	Collaborators	Resources
M. Iredell	Interoperable driver and software framework	Develop and deliver a GFS physics suite and an associated interoperable physics driver that can be used with all NGGPS candidate dycores during Level 2 testing.	Cross-agency input via the NUOPC Physics Interoperability Group	NCEP/EMC base funding and NGGPS supplemental funding, amount TBD

3. **Test and Evaluation Group**

   All SWGs will be supported by the TEG and GMTB. The GMTB will support common processes as defined in Appendix 3 and will support "test harnesses" to promote uniform and consistent procedures and strategies, scripting, data set development and maintenance, component simulators, general software management procedures and NGGPS "trunk" code management. Software-related activities performed by TEG and GMTB will be conducted in close coordination with the NGGPS Overarching System Team and SAET.

Lead scientist(s)	Project Name	Project Description	Collaborators
Team Leader (EMC,TBD)	Test and Evaluation Group	Support SWG development by providing common development processes and strategies. Work with GMTB to contribute, verification codes, component simulators, test harness procedures, data set development, etc.	All SWG members, cross-agency users and code "donators"
Zhuo Wang	Developing physics-oriented diagnostic tools for model evaluation and improvement.	Develop and contribute to GMTB a suite of physics-oriented diagnostic tools for model evaluation; physics-oriented evaluation will not only evaluate the model performance but also reveal the possible error sources.	Cross-agency input from all participating groups.
TBD (EMC)	Data	Develop and contribute to	Data

	assimilation (DA) diagnostics	GMTB a capability to use (O-B) differences and other DA diagnostics to diagnose physical parameterizations, especially for background cloudiness	Assimilation Team(s) at NCEP, NASA, Navy

1.7.2 Long-Term Projects for SWG Development Areas

Information on the long-term Projects for SWG Development Areas is listed below. More details are in Appendix 4.

1. Convection and Boundary Layer

Lead scientist(s)	Project Name	Project Description	Collaborators
Team Leader (TBD)	**Convection and Boundary Layer**	Develop and test new schemes for convection and boundary layer to improve scale-aware capability and scores dependent on these PPs.	All listed Lead Scientists
S. Moorthi	Accelerated implementation of Scale-aware Physics into NEMS	Improve the representations of cumulus parameterization, boundary layer parameterization, and cloudiness. Work will include development by Climate Process Team investigators but focused on weather prediction and demonstrating superiority to operational system.	S. Krueger, D. Barahona
G. Grell & J-W Bao	Scale-aware and Stochastic Convection parameterization	Develop Grell-Freitas scheme for use in GFS physics (see notes in Appendix)	EMC (TBD)
C. Bretherton	Moist EDMF for shallow PBL convection	Refine and test EDMF parameterization in GFS and reduce cloud biases	S. Krueger, J. Teixeira, C. Golaz, EMC (TBD)
S. Krueger	SHOC for PBL turbulence and shallow	Test SHOC, unified (scale-aware) cumulus parameterization and	D. Randall, R. Pincus, S. Lu, C. Bretherton

	convection	improve interaction with microphysics and radiation	

2. Cloud Microphysics

Lead scientist	Project Name	Project Description	Collaborators
Team Leader (TBD)	**Cloud Microphysics Development**	Develop and test new schemes for cloud microphysics and improve interactions with other PPs such as radiation.	All listed Lead Scientists
J.-W. Bao, R. Cifelli	Develop and Evaluate Advanced Microphysics Schemes	Use Single-Column framework and HMT observations to test and evaluate candidate microphysics schemes	EMC (TBD)
	Microphysics support	Support all Cloud Microphysics projects to ensure code integration, testing, coordination across SWGs and TEV meets operational requirements	All Cloud Microphysics PIs

3. Radiation

All NGGPS PP upgrades will require interactions with radiation. Current operational code (RRTMG) is a modern and powerful PP and should be adaptable to requirements from other PPs such as aerosols and deep and shallow convection. There are some questions regarding improved accuracy from spectroscopy research and these should be followed up.

Lead scientist(s)	Project Name	Project Description	Collaborators
Team Leader (TBD)	Improving GFS radiation parameterizations	Support development and use of operational radiation codes to meet requirements of other PPs (e.g., aerosol specification), and improve accuracy of radiation schemes (e.g., improved spectroscopic basis) for improved GFS performance	Funded projects requiring radiation expertise
	Radiation parameterization	Support use of NCEP operational and recently	Funded projects

| | | developed radiation codes to other PPs with requirements for radiation | requiring radiation expertise |

4. Gravity Waves and Large-scale Orographic (and Non-Orographic) Drag

Gravity waves originating in the troposphere and from other sources play a major role in upper atmosphere forecasts and may hold some long-term predictability for the troposphere. At the present time, these connections are on the forefront of research. Nevertheless, the NGGPS should be putting in place the PPs considered important for future predictability, some of which are associated with non-stationary, non-orographically generated gravity waves.

Lead scientist(s)	Project Name	Project Description	Collaborators
TBD	Improving GFS gravity wave, orographic and non-orographic drag parameterizations	Improve GFS accuracy with improved parameterizations of large-scale surface drag, non-orographic drag and gravity waves	TBD (EMC) and NGGPS externally-funded PIs.
T. Fuller-Rowell, V. Yudin, H.Wang	Integrating advanced, unified gravity wave physics	Integrate GW physics in the GFS model for variable vertical and horizontal resolutions and explore treatment of the systematic model errors that can be potentially suppressed by physics-based tune-up of GW parameterizations	R. Akmaev
TBD	Improve upper stratosphere and mesosphere to enhance predictability of long-time scale phenomena	Evaluate and improve QBO, polar sudden warming and model representation of NAO through gravity-wave schemes and other PPs	Gravity-wave PIs

6. Earth System Surface Fluxes and State

The NGGPS focus on forecasting to 30 days necessitates interaction of the atmosphere with other domains over the earth's surface (ocean, waves land and sea ice). The intent of this project is to improve the initial surface state specification and surface flux representation, leaving the evolution of the interior (sub-ground level, ocean boundary layer, etc) to the next phase of the NGGPS project as noted in Section 5.2.4.

Lead scientist(s)	Project Name	Project Description	Collaborators
Team Leader (TBD)	Improved surface fluxes and physics	Improve surface state and fluxes into the atmospheric model for land, ocean, sea ice and glacial ice	TBD
F. Chen	Improving CFS through representation of soil-hydrology-vegetation interactions	Develop upgraded community Noah-MP Land Surface Model	Z-L Liang
TBD	Evaluate and improve surface flux parameterizations	Use data assimilation and parameter estimation algorithms to optimize fits of the background atmosphere to surface observations	EMC Data Assimilation and Land Surface Teams

1.8 Milestones, Resource Requirements, and Outcomes for Long-Term Objectives

Of necessity, the major part of testing the new PP system for the atmosphere must be done first with the uncoupled GSM and again with the new dycore later. As the PP projects mature and a new PP-dycore package is offered for operational implementation, the focus must shift gradually toward testing the NGGPS coupled system. Coupling presents an important and new degree of freedom for the atmospheric system and requires that all of the earth's domains evolve accurately due to this coupling. SWGs will continue to be needed for further development using the coupled system and coordination with other physical systems, (ocean, waves, sea ice, land and ionosphere) will be necessary. Diagnostics using the various data assimilation systems (or a coupled data assimilation system) will continue to be important.

A summary of supplementary NGGPS funding for PP development follows. Funding should be provided for the length of the NGGPS PP development, estimated at 5 years.

Project Name	Contractors
Test and Evaluation Group	5
Cloud Microphysics Development	1
Improving GFS radiation parameterizations	2
Improving GFS gravity wave, orographic and non-orographic drag parameterizations	1
Improved surface fluxes and physics	1
Total	11 EMC Contractors

The development of a physics package is an ongoing effort; if the SWG projects are successful, and the advanced PPs are implemented into operations, sufficient resources must continue to be allocated to support further improvements. EMC will continue to support all new codes to the community to maintain scientific input and further upgrades. EMC will continue to take the lead for final testing and implementation to allow continuity in operations.

Appendix 1
Horizontal Scale Awareness

Many equations describing physical parameterizations do not obey classic convergence properties such as those describing atmospheric dynamics. For instance, equations for grid-scale thermodynamic processes may converge to two solutions, depending on the grid-scale and the fraction of active cloud in each grid box (Figure 1). Since the scales of Numerical Weather Prediction (NWP) models span
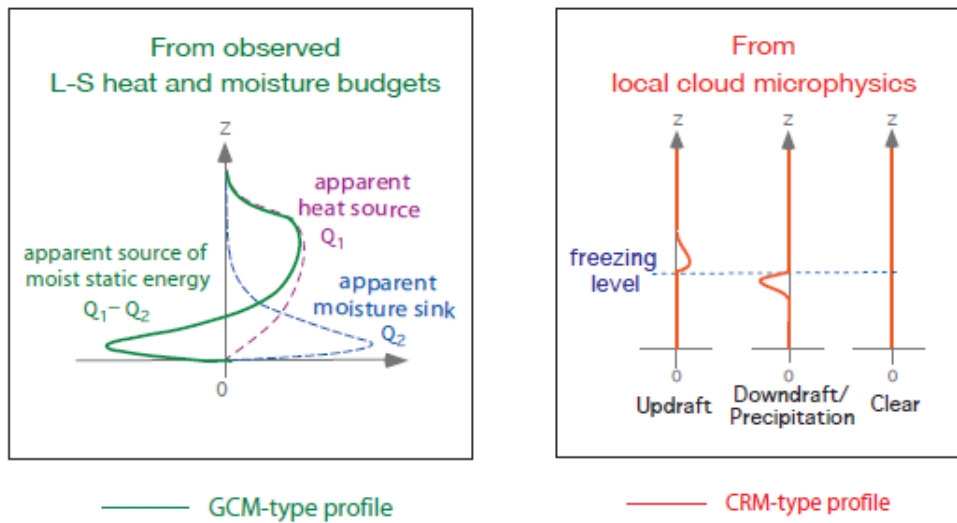

Figure 1. Schematic illustration of typical vertical profiles of cloud moist static energy source under disturbed tropical conditions, from Fig. 3 of Arakawa, Jung and Wu, 2011).

Resolutions that can be occupied by clouds with a full range (0-1.0) of fractional area, cloud parameterization must be "scale-aware."

Appendix 2

Prioritized Areas of Parameterized Physics Development

1. Convection and Boundary Layer

    A. Purpose

      a. Improve the overall conceptual approach to deep convection and Planetary Boundary Layer (PBL) convection by
- Considering PBL convection and turbulence together
- Introducing scale-awareness in horizontal dimension for deep convection and vertical dimension for PBL (stratiform and shallow convection)

    B. Development Activities

      a. Deep Convection

      b. Vertically unresolved shallow, PBL-originated convection

      c. Simplified higher order closure approach for turbulence parameterization, stratiform clouds and shallow convection

      d. Scale-awareness in both deep and PBL convection

      e. Coordinate with Aerosol SWG for cloud-aerosol interactions

      f. Coordinate with Cloud Microphysics SWG on cloud properties and precipitation type

      g. Improved prediction of 2m T, q and 10 m winds, gustiness, PBL depth

      h. Physically-based framework for stochastics

      i. Optimize computational efficiency

2. Cloud Microphysics

    A. Purpose

      b. Improve definition of cloud microphysical content, including cloud properties and precipitation type

    B. Development Activities

      a. Evaluate impact of Single Moment and Double Moment schemes

      b. Add aerosol-aware microphysical processes

      b. Diagnostic algorithm for precipitation type at surface

c. Coordinate with Aerosol SWG on defining cloud-aerosol interactions

d. Coordinate with Radiation SWG on input to radiation parameterization

e. Optimize computational efficiency

3. Radiation

A. Purpose

- Improve accuracy of radiative processes leading to improved weather and climate forecasts

B. Development Activities

a. Improved radiation interactions with cloud macrophysical and microphysical formulations

b. Aerosol interactions

c. Surface radiation balance

c. Improved diagnostics for long-wave and short-wave radiation balance

e. Improved spectroscopy as basis for radiation band modeling

f. Optimize computational efficiency

4. Gravity Waves and Large-scale Orographic (and non-Orographic) Drag

A. Purpose

- Improve representation of gravity wave drag and orographic drag

B. Development Activities

a. Improve model performance in upper stratosphere and mesosphere (will also improve data assimilation in entire vertical column)

b. Develop non-orographic and non-stationary gravity wave drag

c. Scale-aware orographic drag formulation

d. Gravity wave physics that is adaptable to variable horizontal and vertical resolutions

5. Earth System Surface Fluxes and State

A. Purpose

- Improve representation of surface fluxes from all earth domains (land, ocean, sea ice) and the near-surface state of each domain

B. Development Activities

a. Improved parameterized of surface fluxes to and from atmosphere over all domains, including dependencies on wind speed, fetch, vegetation and surface roughness, terrestrial as well as marine (e.g. the effect of ocean waves)

b. Improved skin temperature for all domains (via interaction with the land-surface, and with the upper ocean, ocean mixed layer and below).

c. More complete inventory of surface data from sites over all global domains

d. Maintain SLS compatibility with evolving atmospheric Single-Column Model

e. Improved SST analysis and forecast

f. Coupled hydrological processes such as river flow, ground water, irrigation etc.

g. Improve sea ice physics representation, including radiative, heat, melt-water fluxes

Appendix 3
Development Infrastructure Functions and Resources

Basic development functions for all projects include:

1. Executing jobs, including scripting development, disk management, job coordination, monitoring and prioritization;
2. Code management and coordination between all projects;
3. Diagnostics tools development;
4. Code maintenance, including EMC standard codes and newly developed codes;
5. Development and maintenance of component simulators such as a SCM and SLS; and
6. Verification, including development and integration of new metrics.

The NGGPS Overarching System Team and SAET will work closely with EMC to provide leadership on strategies for code management, development best practices, and standardization of scripts and data management. The SWGs will interface closely with those teams to make sure the physics development, as well as the innovations contributed by other NGGPS groups (CPO CPTs and others), is well integrated within the NGGPS software structure.

The TEG work will connect the SWGs work with that and other NGGPS groups working on verification and diagnostics, such as GMTB and the Verification Team.

Appendix 4

Science-based Working Group Projects

The following template is used to specify information for each NGGPS PP project.

- **Lead Organization**:
- **Activities**:
- **Milestones and deliverables**:
- **Resource requirements**:
- **Anticipated collaborating organizations**:
- **Priority**:
- **Duration**:
- **Points of contact**:

1. **Conduct a physical parameterization workshop.**

COMPLETE

   - **Lead Organization**: Hosted by NCEP, with logistical support from DTC.
   - **Activities**: Review current state of the science.
   - **Milestones and deliverables**: Discuss focus areas for formulation of a 5-year technical plan/draft report.
   - **Resource requirements**: Project office will supplement travel.
   - **Anticipated collaborating organizations**: Multiple cross-agency participation.
   - **Priority**: High.
   - **Duration**: 3 days.
   - **Points of contact**: Jim Doyle (Naval Research Laboratory) and Robert Pincus (U. of Colorado).

2. **Deliver interoperable driver and software framework for testing the evolving GFS physics suite and NGGPS Level 2 requirements.**
   - **Lead Organization**: NCEP/EMC.
   - **Activities**: Develop and deliver a GFS physics suite and an associated interoperable physics driver that can be used with all NGGPS candidate dycores during Level 2 testing.
   - **Milestones and deliverables**: Deliver by June 2015.
   - **Resource requirements**: NCEP/EMC base funding and NGGPS supplemental funding via SciTech contract.
   - **Anticipated collaborating organizations**: Cross-agency input via the NUOPC Physics Interoperability group.
   - **Priority**: High.
   - **Duration**: Completion 06/2015.
   - **Points of contact**: Mark Iredell (NCEP/EMC)

3. **Test and Evaluation Group (TEG)**
   o **Lead Organization**: NCEP/EMC.
   o **Activities**: Support SWG development by providing common processes, codes and management of HPC, including
      ▪ Executing jobs, including scripting, disk management, job coordination, monitoring and prioritization
      ▪ Providing test strategies including choice of horizontal resolution, etc
      ▪ Providing common code management environment and procedures for all projects
      ▪ Improving and maintaining important tools such as the Surface Layer Simulator (SLS) and Atmospheric Single Column Model (SCM)
      ▪ Develop enhanced diagnostics, including EMC standard codes and newly developed codes
      ▪ Verification, including development and integration of new metrics and supporting data sets
   o **Milestones and deliverables**: Establish functions and resources requirements for supporting 6 WGs by June 2015. Semi-annual report of all experiments executed and delivery of all results within 1 month of experiment conclusion; code and script management for all experiments
   o **Resource requirements**: NGGPS supplemental funding via SciTech contract; Funding TBD.
   o **Anticipated collaborating organizations**: Cross-agency input from all participating groups
      ▪ **Group members:**
         • Diagnostician - TBD
         • Verification lead - TBD
         • Execution manager (scripting, disk management, job monitoring) - TBD
   o **Priority**: Highest.
   o **Duration**: Throughout entire development project.
   o **Points of contact**: TBD (NCEP/EMC)

Associated Proposal: Developing physics-oriented diagnostic tools for model evaluation and improvement.
   o **Lead Organization**: Zhuo Wang - Lead PI, University of Illinois.
   o **Activities**: Develop a suite of physics-oriented diagnostic tools for model evaluation. Different from the performance-oriented metrics, physics-oriented evaluation will not only evaluate the model performance but also reveal the possible error sources.
   o **Milestones and deliverables**: Expected outcome of the project is a suite of diagnostic tools with general applicability across models. The diagnostic package

will be transitioned to modeling centers for a systematic physics-oriented evaluation of different models. The diagnostic tools will also be made available to the general research community to facilitate studies on the variability and predictability of extreme weather events.

- o **Anticipated collaborating organizations**: Co-PIs: Glenn White (EMC), Stan Benjamin, NOAA Earth System Research Laboratory (ESRL), Global Systems Division; Melinda Peng, Naval Research Laboratory (NRL) Monterey; Ming Zhao, NOAA Geophysical Fluid Dynamics Laboratory (GFDL). Collaborator: Shiann-Jiann Lin, NOAA/GFDL.
- o **Priority**: High.
- o **Duration**: 05/01/2015-04/30/2017.
- o **Points of contact**: Zhuo Wang (zhuowang@illinois.edu).

4. **Convection and Boundary Layer**

   Associated Proposal: Accelerated Implementation of Scale-aware Physics into NEMS.
   - o **Lead Organization**: Dr. Shrinivas Moorthi – Lead PI and Dr. Yu-Tai Hou – Co-PI, GCWMB, NCEP/EMC.
   - o **Activities**: Improve the representations of cumulus parameterization, boundary layer parameterization, and cloudiness. Work will include development by Climate Process Team investigators but focused on weather prediction and demonstrating superiority to operational system.
   - o **Milestones and deliverables**:
       - Implement unified cumulus parameterization in GSM and test - May 2015
       - Implement microphysics in GSM and preliminary test - Nov 2015
       - Start making low resolution coupled runs - Dec 2015
       - Start evaluating the new model through parallel tests with data assimilation at relatively low resolution - evaluate and tune - May 2016
       - Start evaluating at operational resolutions - Aug 2016
       - Evaluate in coupled climate mode - Nov 2016.
   - o **Anticipated collaborating organizations**: Co-PI: Prof. Steven K. Krueger, University of Utah. Collaborator: Dr. Donifan Barahona, GMAO/GSFC/NASA.
   - o **Priority**: High.
   - o **Duration**: (Proposed 2 years)
   - o **Points of contact**: Dr. Shrinivas Moorthi (shrinivas.moorthi@noaa.gov).

   Associated Proposal: Further Testing and Evaluation of a Scale-Aware Stochastic Convection Parameterization in NOAA's Next Generation Global Prediction System.
   - o **Lead Organization**: Georg Grell and Jian-Wen Bao – Co-PIs, NOAA/ESRL.

- o **Activities**: First, implement the Grell-Freitas (GF) scheme into NOAA's GFS model. Next, a detailed evaluation will be done with a single well-documented tropical storm case study using different horizontal and vertical resolutions. A special focus will be on scale awareness and interaction with other physical parameterizations (boundary layer, radiation-cloud coupling, microphysics coupling). Results will also be compared with simulations using the convective parameterization that is currently used in the HWRF physics package. The final stage in the second year will include evaluation in terms of track forecasts and hurricane intensity, as well as implementation and evaluation in a possible future dynamic core of NGGPS.
- o **Milestones and deliverables**: Implementation into HWRF will be finished in the first quarter of the project. The second quarter will focus on evaluation with a single documented case study. A publication for a refereed journal should be completed in the fourth quarter. Additionally, evaluation in terms of track and intensity forecasts during a hurricane season will be the focus of the third and fourth quarter of the first year. A publication describing the results of the track and intensity forecasts is expected to be submitted by the end of the second quarter of the second year. Implementation into a possible future dynamic core will be done in the third quarter of the second year. Evaluation will conclude this work and will also include a focus on other skill measures of global modeling systems that are currently used at EMC.
- o **Anticipated collaborating organizations**: NOAA/NCEP.
- o **Priority**: High.
- o **Duration**: Proposed 2 years.
- o **Points of contact**: Georg Grell (Georg.A.Grell@noaa.gov).

Associated Proposal: Moist EDMF for shallow PBL convection
- o **Lead Organization**: Chris Bretherton, U. of Washington
- o **Activities**:
  - ▪ Reduce global cloud biases in GFS
    - • Improve GFS microphysical parameterizations,
    - • Improve cloud fraction parameterizations
    - • *Advancing GFS parameterizations related to shallow cumulus cloud*
    - • Multi-decade coupled GFS+MOM4 climate simulations
  - ▪ Test and refine a moist eddy-diffusivity mass-flux (EDMF) in GFS
    - • Year 1: implement and evaluate the new moist EDMF parameterization into the GFS Single Column Model (SCM).
    - • Year 2: implement and evaluate the new moist EDMF parameterization in global climate-mode simulations.

22

- Year 3: develop a version of moist GFS that improves the coupled climate of the GFS, and then try to refine it to also perform optimally in a weather forecast mode.
  - Compare cloud cover in short range (0-5 day) GFS and GFDL hindcasts
- **Milestones and deliverables**:
  - Improved GFS and next generation CFS with reduced global cloud biases
  - Improved representation of cloud-topped boundary layers and their role in the initiation of deep convection over land
- **Anticipated collaborating organizations**:
  - Current co-PIs (JPL- Teixeira, GFDL- Golaz, , NCEP - Han)
  - Other CPTs (Krueger; Lu)
- **Priority**:
- **Duration**: 8/1/13 – 7/31/16

Points of contact: Chris Bretherton: breth@washington.edu

Associated Proposal: SHOC (Simplified Higher Order Closure) for PBL turbulence and shallow convection and advanced scale-aware deep convective parameterization

- **Lead Organization**: Steven Kruger, U. of Utah
- **Activities**: Test and implement the following schemes in NCEP GFS/CFS:
  - Install and test SHOC in the GFS/CFS, that would replace many aspects of the boundary layer turbulence scheme, the shallow convection scheme, and the cloud fraction scheme;
  - Test the unified cumulus parameterization in GFS/CFS, which allows a model to simulate individual clouds when and where the grid spacing is sufficiently fine, while acting as a conventional parameterization of deep convection when and where the grid spacing is coarse. The unified parameterization has been evaluated by using results from the high-resolution simulations
  - Improve the representation of the interactions of clouds, radiation, and microphysics in the GFS/CFS by coupling the distribution predicted by the sub-grid scheme to radiation using a well-established algorithm, and exploring the coupling to microphysics using a range of analytic and Monte Carlo techniques.
- **Milestones and deliverables**:
  - A PDF-based SGS turbulence and cloudiness scheme.
  - A unified cumulus parameterization scheme, one that allows the updraft area fraction to be any value from 0 to 1.
  - An improved representation of the interactions of clouds and radiation in the GFS/CFS.
- **Anticipated collaborating organizations**:
  - Current co-PIs (CSU- Randall, UC- Pincus; NCEP- Moorthi)
  - Other CPTs (Bretherton; Lu)
- **Priority**:
- **Duration**: 8/1/13 – 7/31/16
- **Points of contact**: Steven K. Krueger,: steven.krueger@utah.edu

5. Cloud Microphysics

Associated Proposal: Evaluating the Impact of Cloud-Aerosol-Precipitation Interaction (CAPI) Schemes on Rainfall Forecast in the NGGPS.

- o **Lead Organization**: Zhanqing Li – Lead PI and Seoung-Soo Le (Co-PI), University of Maryland.
- o **Activities**: Implement, as needed, (and evaluate) a suite of new physical schemes such as the Morrison and Gettelman two-momentum cloud microphysical scheme into the NCEP's Next-Generation Global Prediction System (NGGPS) .
- o **Milestones and deliverables**:
    - ▪ Evaluating the performance of the new physical schemes associated with accounting for the aerosol effects that affect rainfall forecasts and cloud simulations through in-depth comparisons with extensive global satellite and ground-based products and observation-based findings.
    - ▪ Understanding the causes of discrepancies in simulating clouds and their interactions with aerosols between current and new schemes, and between model simulations and observations by virtue of a high-resolution cloud-resolving model (CRM).
    - ▪ Evaluating the gross features of NGGPS simulations through comparisons with satellite and surface measurements with reference to aerosol loading and types.
    - ▪ Understanding the performance and improvement of the impact of the parameterization schemes on CAPI by using CRM and single column model (SCM) simulations for convective and stratiform cloud systems.
- o **Anticipated collaborating organizations**: Co-Investigators: Yu-Tai Hou, Jun Wang, Shrinivas Moorthi (NOAA EMC) and Sarah Lu (State University of New York, Albany).
- o **Priority**: High
- o **Duration**: 05/01/2014 - 04/30/2017.
- o **Points of contact**: Zhanqing Li (zli@atmos.umd.edu).
  * Note: The above proposal is also listed in the NGGPS Aerosol Team Plan for cross-reference.

Associated Proposal: Evaluation and Adaptation of Advanced Microphysics Schemes in NOAA's Next Generation Global Prediction System Using the NOAA-HMT Observations.

- o **Lead Organization**: Jian-Wen Bao/Rob Cifelli - Co-PIs, NOAA/ESRL/PSD.
- o **Activities**: Five advanced bulk microphysics schemes (BMSs) that are widely-used in numerical weather prediction models will be implemented, compared and evaluated in a single-column model framework based on the physics packages

currently used in NOAA's GFS global models. The forcing to this single-column model is provided from the GFS and NMM-B models' output. Also included will be the double-moment cloud microphysics scheme (Morrison and Gettleman, 2008; Barahona et al., 2014) as an option.

- o **Milestones and deliverables**:
    - Finish testing the aforementioned five BMSs into the proposed single column model with the physics packages of and forcing derived from the GFS and/or NMM-B models by the end of the first 6 months in Year 1.
    - Finish the comparison of the results from the single-column model simulations against the NOAA-HMT observations by the end of the second 6 months in Year 1.
    - Finish the proposed hydrometeor budget analysis and comparison by the end of the first 6 months in Year 2.
    - Finish the proposed investigation of the five schemes with respect to the diurnal cycle of simulated heavy rainfall and the relationships between hydrometeor size distributions and rainfall rates; and make a recommendation on the choice of the single-moment vs multi-moment schemes to be adapted into the NGGPS and further improvement of the chosen scheme along with additional testing of the scheme of choice in the NMM-B model by the end of the second 6 months in Year 2.
- o **Anticipated collaborating organizations**: Collaborators: Brad Ferrier and Eric Aligo, NOAA/NWS/EMC.
- o **Priority**: High
- o **Duration**: Proposed 2 years.
- o **Points of contact**: Jian-Wen Bao (Jian-Wen.Bao@noaa.gov).

Associated Proposal: Improving cloud microphysics and their interactions with aerosols in the NCEP Global Models
- o **Lead Organization**: Sarah Lu – Lead PI, University of Albany, SUNY.
- o **Activities**: Conduct a two-year research-to-operations project to the NOAA MAPP Program to enhance the NOAA/NCEP weather-climate modeling capabilities by improving the representations of cloud microphysics, aerosol processes, and aerosol-cloud-radiation interactions in the NCEP global models (i.e., the Global Forecast System, GFS, and the Climate Forecast System, CFS). NASA GMAO is revamping the existing treatments of clouds and aerosols in Goddard Earth Observing System Model, Version 5 (GEOS-5) by introducing a double-moment cloud microphysics scheme (Morrison and Gettleman, 2008) and coupling it with a modal aerosol model (Liu et al., 2012). Both schemes are developed and implemented in the Community Atmosphere Model (CAM5.1), the atmospheric component of the Community Earth System Model (CESM)

primarily at the National Center for Atmospheric Research (NCAR). This project will adopt the physically-based cloud/aerosol package at GMAO, which in turn will leverage scientific advances by a broad climate research community.

- o **Milestones and deliverables**: This project will contribute toward achieving the first of NOAA's Next Generation Strategic Plan climate objectives, an improved scientific understanding of the changing climate system and its impacts, by improving two core capabilities: understanding and modeling, and predictions and projections.
- o **Anticipated collaborating organizations**: Co-PI(s): Yu-Tai Hou, NOAA/EMC; Arlindo da Silva, NASA/GSFC; Shrinivas Moorthi, NOAA/NCEP; Fanglin Yang, NOAA/NCEP; Qilong Min, University of Albany, SUNY; Anton Darmenov, NASA/GSFC; Donifan Barahona, NASA/GSFC.
- o **Priority**: High.
- o **Duration**: Two-year project.

Points of contact: Sarah Lu (clu4@albany.edu).

* Note: The above proposal is also listed in the NGGPS Aerosol Team Plan for cross-reference.

6. **Radiation**

All NGGPS PP upgrades will require interactions with radiation. Current operational code (RRTMG) is a modern and powerful PP and should be adaptable to requirements from other PPs such as aerosols and deep and shallow convection. There are some questions regarding improved accuracy from spectroscopy research and these should be followed up.

7. **Gravity Waves and Large-scale Orographic (and Non-Orographic) Drag**
   Associated Proposal: Integrating Unified Gravity Wave (GW) Physics into the Next Generation Global Prediction System.

- o **Lead Organization**: Dr. Timothy Fuller-Rowell – Lead PI, University of Colorado. Dr. Valery Yudin and Dr. Houjun Wang – Co-PIs, University of Colorado.
- o **Activities**: Integrate GW physics in the NEMS atmosphere models for variable vertical and horizontal resolutions. This will require resolution-aware formulations of GW schemes. Work to improve the weather and climate simulations and explore treatment of the systematic model errors that can be potentially suppressed by physics-based tune-up of GW parameterizations, as shown by recent successes of research simulations. This work will be introduced during the two-year collaborative project between CU-CIRES and NOAA/NWS test-bed centers.

- o **Milestones and deliverables**: Year 1: Porting and testing unified suite of GW schemes in NEMS. Year 2: Evaluations of GW physics in updated atmosphere models: sub-seasonal predictability.
- o **Anticipated collaborating organizations**: Co-Investigators: Dr. Jordan Alpert, NOAA EMC; Dr. Rashid Akmaev (SWPC).
- o **Priority**: High.
- o **Duration**: 05/01/2015-04/30/2017.
- o **Points of contact**: Dr. Timothy Fuller-Rowell (timothy.fuller-rowell@colorado.edu).

8. Earth System Surface Fluxes and State

Associated Proposal: Improving the NCEP Climate Forecast System (CFS) through Enhancing the Representation of Soil-Hydrology-Vegetation Interactions.
- o **Lead Organization**: Hosted by NCEP, with logistical support from DTC.
- o **Activities**: Improve the NCEP Climate Forecast System (CFS) forecast skill by enhancing the representation of soil-hydrology-vegetation interactions through the use of the new community Noah-MP (Multiple-Parameterization) land surface model (LSM). Leverage the ongoing work of the NCEP/EMC land team regarding the testing of Noah-MP v1 in CFS v2 and further evaluate and improve the newly released community Noah-MP v2, and address the overall scientific and operational questions: To what degree can a more accurate representation of soil-hydrology-vegetation interactions improve CFS seasonal predictions?
- o **Milestones and deliverables**:
    - ▪ Task1: Benchmark performance of CFS v2 hindcast using different land models for a selection of nine years using the NCEP verification metrics.
    - ▪ Task 2: Explore Noah-MP physics-ensemble forecasting by conducting numerous uncoupled GLDAS and coupled CFS hindcast experiments with different configurations of Noah-MP physics options.
    - ▪ Task 3: Analyze ensemble spread and determine an optimal set of Noah-MP physics options that can maximize the CFS forecast evaluation metrics. Ascertain whether an optimal set of Noah-MP physics exists and, if so, how it should be used in CFS.
    - ▪ Task 4: Understand the impact of soil-hydrology-vegetation seasonal prediction skill.
- o **Anticipated collaborating organizations**: Collaboration with NCEP, CFS, and Climate Test Bed teams. Co-PI(s): Zong-Liang Yang, University of Texas at Austin; Michael Ek, NOAA/EMC; Rongqian Yang, NOAA/EMC; Jesse Meng, NOAA/EMC.
- o **Priority**: High.
- o **Duration**: Two-year project.
- o **Points of contact**: Fei Chen (feichen@ucar.edu).