UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

Office of Science and Technology Integration
1325 East-West Highway, Silver Spring, MD 20910-3280, USA

2016 Roadmap for the Production Suite at NCEP

Draft Version 0.6
December, 2016
Hendrik L. Tolman, Editor

1 Introduction

1.1 Purpose

This document describes a strategic roadmap for the evolution of the suite of operational computer models[1] that are run every day by the National Centers for Environmental Prediction (NCEP) in support the mission of National Weather Service (NWS) in particular, and the National Oceanic and Atmospheric Administration (NOAA) in general. It covers the next 5 to 10 years, and focuses and expands on the general Strategic Plan (SP) or vision that is presented elsewhere. It does not address most details of its final implementation, nor does it discuss the transition to a new layout of this model suite. The latter will be addressed in the Strategic Implementation Plan (SIP), which is a companion to the SP and this Roadmap. By nature, the SP, Roadmap and SIP are living documents.

[1] Including data assimilation, processing of observations, post-processing etc.

1.2 Background

Numerical modeling guidance has been the cornerstone of weather forecasting for decades. The models used by the NWS for operational weather forecasting are generally denoted as “operational” models, and are run on a fixed schedule by NCEP Central Operations (NCO). The set of models run in this way is referred to as the Production Suite at NCEP (PSN). Several organizations other than NCEP contribute to the PSN, most notably the NWS Meteorological Development Laboratory (MDL), the NWS Office of Water Prediction (OWP), The Oceanic and Atmospheric Research (OAR) Air Resources Laboratory, (ARL), Geophysical Fluid Dynamic Laboratory (GFDL) and Earth System Research Laboratory (ESRL) and the National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS).

External reviews for NCEP (UCACN, 2009, UCACN, 2011-2015) have long observed that the PSN is too complicated and needs to be simplified. In response to this the NCEP director charged the UCAR Community Advisory Committee for NCEP (UCACN) to stand up the UCACN Model Advisory Committee (UMAC) in 2015. The charge of UMAC was to review the entire PSN. This review was performed in August of 2015, and the UMAC provided its report back to NCEP December 7, 2015 (UMAC, 2015). Key findings of the UMAC are the need for simplifying the PSN, and the need to have a detail strategic plan to do so. The SP, Roadmap and SIP are developed in direct response to these recommendations.

Figure 1 shows the production suite as of August 2016. This production suite evolved over decades as a set of solutions (models) for individual problems, rather than through a systematic approach of providing products to satisfy requirements. This resulted in a quilt of models, with multiple model approaches with overlapping functions and products. The end goal is to move from this quilt of models to a unified modeling approach. Such a system focuses limited resources on a smaller number of models, allowing a faster improvement of the elements of the productions PSN, as well as the PSN as a whole.

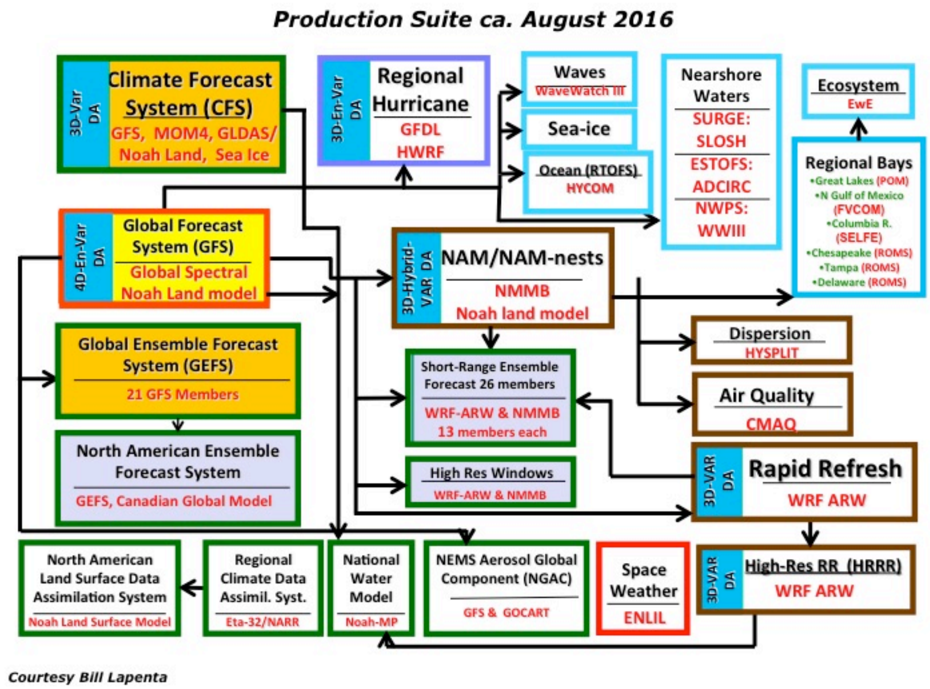


Figure 1: Production Suite ca. August 2016

2 Basic Concepts

2.1 Introduction

This section of the Roadmap addresses basic concepts used to develop a new strategic design for a Unified PSN. These basic concepts follow from internal discussions mostly within the NWS and OAR, and were both confirmed and expanded upon by UMAC.

2.2 Unified Modeling and Data Assimilation

The ultimate vision for a Unified PSN is an integrated modeling system that unifies scales from convection-resolving weather (hour outlook)to climate (1 year outlook), and integrates environmental subcomponents for weather, oceans, land, ice, hydrology etc. in a scientifically sound, and economically justifiable way to most efficiently support NOAA's operational mission. The dominant goal associated with this vision is to simplify the present quilt of operational models as illustrated in Figure 1.

2.2.1 Product and requirement based

The disparate quilt of models that represent the present PSN (Figure 1) developed over decades as new solutions (models) were added to the suite, typically as "stovepipes" serving selected user groups and championed by developers in competition with other elements of the PSN. This has resulted in many models with overlapping products based on disparate modeling approaches. This is particularly true for mesoscale weather models, where as many as seven different models have been used (often side-by-side), in the last two decades.

Moving to a simplified production suite requires a ***product focused*** design, where ***requirements*** drive technical development foci, using models that are adopted to provide the required products.

Having a product-oriented PSN requires a corresponding strategic design (the SP and Roadmap), a plan to implement such a design (the SIP), but most importantly, a governance structure that strongly enforces a product-based approach, and avoids one-off model implementations unless there is a solid science/business case to do the later.

2.2.2 Unified Modeling Approach

A product-oriented PSN naturally leads itself to a unified modeling approach. At the least, one modeling system supports each set of consistent products. However, following the lead of leading weather centers, in particular the UK MetOffice (UKMO), a unified approach across scales is preferable, using a single unified modeling system from climate time scales (year time scale) to Convection Allowing Models (CAM, hour time scale).

Unified modeling principles are described in a whitepaper of the NOAA Unified Modeling Task Force (NUMTF, 2016), and imply that modeling efforts are focused on a minimum set of models, driven by scientific and business principles. It ***does not*** imply unitary modeling, where the first goal is to focus on a single model.

2.2.3 Key elements of the PSN

Traditionally, the main focus of the PSN has been on weather and climate elements. Other environmental sub-components are present in the NSP. Most of these sub-components satisfy specific mission requirement of NOAA. The PSN is continually evolving, and three key elements of the PSN beyond traditional weather applications need to be considered strategically.

Environmental sub-components and coupling

The present PSN contains products and models for land/hydrology, oceans (coasts), sea ice, waves, aerosols, marine ecosystems and space weather. Historically, these systems are treated as stand-alone environmental sub-systems. Starting with climate applications, these systems are considered more and more as coupled holistic environmental systems, both to provide required products for sub-systems, and to improve the overall quality of all products due to data exchange between sub-components. With this in mind, a Unified PSN will be inherently coupled across environmental sub-components. This is discussed in more detail in Appendix A.

Ensembles

A key aspect of the PSN is the use of ensembles or forecast uncertainties. Uncertainty is a fundamental characteristic of weather, seasonal climate, and hydrological prediction, and no forecast is complete without a description of its uncertainty (US NRC Report - Completing the Forecast, 2006). Ensembles are used for providing assessments of forecast uncertainty on weather, week-2 and seasonal forecast ranges. Given the greater value of probabilistic forecasts compared to the traditional single deterministic forecast, all future guidance products will be ensemble based. Control runs of an ensemble are ideally of the same resolution as the ensemble itself. This avoids the historical tendency of forecaster to consider the control run as the deterministic model of choice, and will help move forecasters away from the more general "model of the day" approach.

Reforecast and reanalysis

Another recently added element of the PSN is the availability of Reforecasts and Reanalyses (RRs) of ensemble products. Such RRs provide a clear benefit in terms of calibrating ensemble outlook products. More recently, RRs are used for Impact-based Decision Support Services (IDSS) as part of the Weather Ready Nation (WRN) focus of the NWS [add WRN reference] Once the entire PSN is ensemble based, the traditional retrospective testing of new model implementations will naturally obtain the characteristics of RRs.

2.3 Evidence driven approach

One of the key findings of UMAC states that "*The NOAA environmental modeling community requires a rational, evidence-driven approach towards decision-making and modeling system development.*" Key decisions on architecture, scientific selection (e.g., dynamics, physics, data assimilation (DA)), etc. will therefore be based on objective validation and verification, and not on assertion. This requires the establishment of ***requirements***, agreement on ***validation metrics***, and a unified approach to computing such metrics.

2.4 Community approach

The new PSN will use a community modeling approach that involves NOAA, other federal partners (e.g., NASA, JCSDA, DoD, etc.[2]), and the research and academic community at large. Only with appropriate contributions from the entire U.S. modeling community will we be able to build the best ***national*** modeling system possible.

The ***definition*** of "community" is important, and not all community efforts are be identical. Prior community modeling efforts (ECMWF, WRF, CESM, WW3, etc.) show both strengths and weaknesses of different approaches, and that one size does not fit all. The community approach will include training and support (e.g., help desks and/or support groups), and may be formalized in approaches and organizations such as the Developmental Testbed Center (DTC).

The unified modeling system will be built to support the needs of both ***operations*** and ***research***, with a well-defined path for transitioning research to operations. Without that linkage, the incentives for the research community to participate will be sub-optimal.

Best practices have shown that different levels of community partners should be established, with specific roles/responsibilities for each. For example:

[2] Initial community modeling efforts for the PSN such as WAVEWATCH III also include international partners such as the UK Met Office (UKMO) and foreign universities.

- Trusted super-users may be established that have different access than occasional research users.
- Core development partners that regularly make substantial contributions have different roles than casual “users” that run the model but not contribute to development.
- Users and stakeholders, while not contributing to the code in general, contribute requirements and needs, and drive the direction of development, resources allocations and prioritization (within the NOAA mission).

The unified modeling system has to be a national system where all core partners have true ownership. As such, each core partner has to treat their role on the national team as a fundamental and enduring priority for their respective organization, supported where appropriate with internal core resources. This unified modeling system will form part of NOAA’s modeling contribution to the National Earth System Prediction Capability (National ESPC), which extends from weather to decadal scales, and will be able to leverage interagency partnerships coordinated by National ESPC.

2.5 Governance

With the community approach to modeling the elements of the PSN, all core partners will have a voice in making strategic decisions, not just the operational center(s). With the PSN being heavy on weather applications, the governance process is coined here first in terms of the formal NWS governance process [reference to governance 2.0]. The NWS governance identifies three key steps.

1. Establish service requirements and associated products, where the products define the core of the Unified PSN. Within the NWS, the appropriate vehicle to define and validate (service) requirement is the CaRDS process [add reference].
2. Determine scientific requirement and possible solutions. Within the NWS this task falls with the Office of Science and Technology Integration (OSTI), Within the PSN, this task is shared by the team managing the PSN applications, with input from NOAA operations and research, and where appropriate, the research community external to NOAA.
3. Solutions for requirements are prioritized within the NWS by the Mission Delivery Council (MDC, [reference to governance 2.0]). A process for dealing with prioritizing non-NWS work in the PSN is not yet in place.

This governance structure is aligned with UMAC recommendations. For step 2 UMAC recommends to establish “review boards” to govern the development of key elements of the PSN. For step 3 UMAC recommends a holistic approach to governing the entire PSN.

3 The Big Picture

3.1 Introduction

Section 3 steps through the key elements of a high-level roadmap plan based on the basic concepts laid out in Section 2. Section 3.2 starts with looking at ranges of forecast products in the PSN, as required by our main stakeholders. Section 3.3 discusses the resulting high-level design of a new unified PSN. Section 3.4 discusses the underlying system architecture, with a focus on coupling subcomponents in a holistic environmental modeling approach. Unification of the sub-components is discussed in Section 3.5, and Section 3.6 goes back to the core elements of the proposed unified PSN. The latter section overlaps somewhat with the SIP, as it identifies tentative details of the core models applications in the PSN such as spatial resolution and ensemble sizes. This is needed in the present SP to address resource needs and hence the high-level feasibility of this strategic plan.

3.2 Products

The first step to move from the quilt of Figure 1 to a unified PSN is to start with products rather than solutions. Because the PSN is and is expected to remain heavy on weather products, the initial focus is on weather products.

An analysis of present products in the PSN, along with a discussion with the main stakeholders at the December 2015 NCEP Production Suite Review, identified 6 temporal product ranges as presented in Table 1. The first five ranges consist of analyses / Data Assimilation (DA) and models. The "Now" (nowcast) products are focused on an analysis that represent observations in the most accurate way, and are not intended to initialize models. Whereas the same tools may be used for DA model initialization and nowcasts, these two products are nevertheless systematically different products, and hence separate applications in the PSN

Table 1: Product ranges for a new PSN

Range	Target	Cadence	Forecast
Year	Seasonal	7 days	9-15 mo.
Month	S2S, week 3 and 4	24 h	35-45 d
Week	Actionable weather	6 h	5-8 d
Day	Convection Resolving	1 h	18 h
Hour	Warn on Forecast	5-15 min	2-4 h
Now	Analysis	5-15 min	---

3.3 High-level design

The above considerations result in a high-level layout of a new PSN as presented in Figure 2, which can tentatively be achieved in 5-10 years. From the global perspective, development moving to this design has already been started in the Next Generation Global Prediction System (NGGPS) project (Toepfer et. al., 2014). Table 1 is focusing on weather products in the PSN. As discussed in the Section 2 and in Appendix A other ***coupled*** components, ***ensembles***, and ***reforecasts and reanalyses*** are an integral part of the unified PSN.

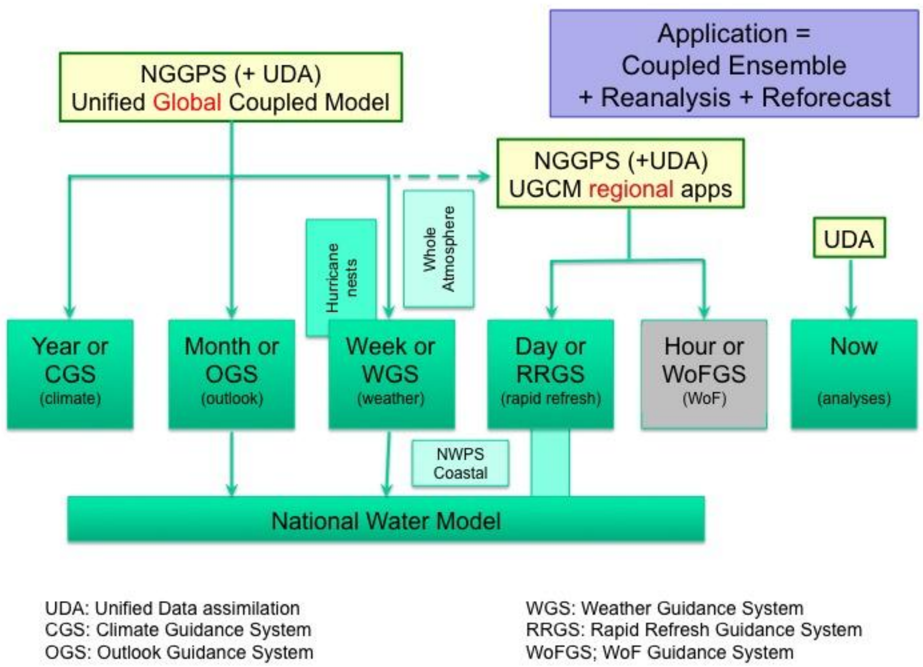


Figure 2: High-level Unified PSN design

The Climate, Outlook and Weather Guidance Systems (CGS, OGS and WGS) are inherently global. These three applications will all be based on a single Unified Global Coupled Model (UGCM), and a Unified Data Assimilation (UDA) approach. Note that a global approach does not preclude the use of variable resolutions with a focus on the mission areas for NOAA, e.g., CONUS, Alaska, Hawaii, Guam Puerto Rice, as presently in the PSN, or relocatable nests as presently used for fire weather and hurricanes.

The convection allowing Rapid Refresh and Warn on Forecast Guidance Systems (RRGS and WoFGS) are inherently regional. Ideally, the regional products are generated by regional applications of a single UGCM. As observed by the UMAC, it may be necessary to have separate unified regional and global modeling systems as we transition to a fully unified approach.

The CGS, OGC, WGS, RRGS, WoFGS and analyses (nowcasts) form the core of the unified PSN in Figure 2. A review of the present PSN shows that not all present products in the PSN fit into this structure. Such elements include hurricane models, space weather, the National Water Model (NWM), the Nearshore Wave Prediction System (NWPS), coastal models, on-demand air quality models, and models driven by data from the National Digital Forecast Database (NDFD). These elements are identified individually in Figure 2, and are discussed in more detail in Appendix B.

3.4 Architecture (coupling)

A critical element of a unified approach it the use of overall system architecture, particularly for coupling. An essential feature of a coupled modeling strategy is that is allows for efficient coupling of environmental subcomponents, while minimizing the additional burden that coupling places on development of the individual subcomponents. This naturally leads to a modular approach, where each component has a clear interface and can be built separately, and where subcomponents are generally linked through an external coupler / mediator. An additional benefit of a modular approach for an operational environment is that different levels of coupling (including phasing in as the forecast time progresses) can be used for different applications of a single unified modeling system by manipulating the coupler / mediator only.

This modular approach is generally identified as "loose" coupling. Its major disadvantage is that short time scales of interactions or large volumes of data exchanges associated with interactions between subcomponents make a modular approach less suitable and efficient than a single, integrated code for multiple sub-systems [add references to wave-stormsurge and ocean-ice coupling]. For the period covered by this strategic plan, where coupling approaches in general are not yet mature, the benefits of a modular approach far outweigh its potential disadvantages.

US government agencies (e.g. NASA, the Department of Defense, NOAA, the National Science Foundation) have invested in the development of the Earth System Modeling Framework (ESMF, Theurich, et al., 2016), which provides an architecture and tool set for modular coupled modeling. The National Unified Operational Prediction Capability (NUOPC, Sandgathe, et al., 2011) effort standardized component interfaces in ESMF in the so-called NUOPC layer, to facilitate "plug-and-play" coupling approaches where different models for a given environmental sub-component can be exchanged relatively easily. NCEP has invested in the NCEP Environmental Modeling System (NEMS, [add reference(s)]) as a general coupler / mediator environment based on ESMF and the NUOPC layer, in close collaboration with ESRL. The ESMF-NUOPC-NEMS approach to unified modular coupled modeling was endorsed by UMAC and its general layout is illustrated in Figure 3. ESMF and NUOPC are mature inter-agency approaches, and are increasingly adopted by academia (e.g., NCAR's CESM [add reference]), and is consistent with the National ESPC approach (Carman, et. al., in press). NEMS is less mature, and its approaches will need to be revisited periodically. The separation of the dynamic core and physics for the atmosphere as introduced in will be discussed in Section 3.5.

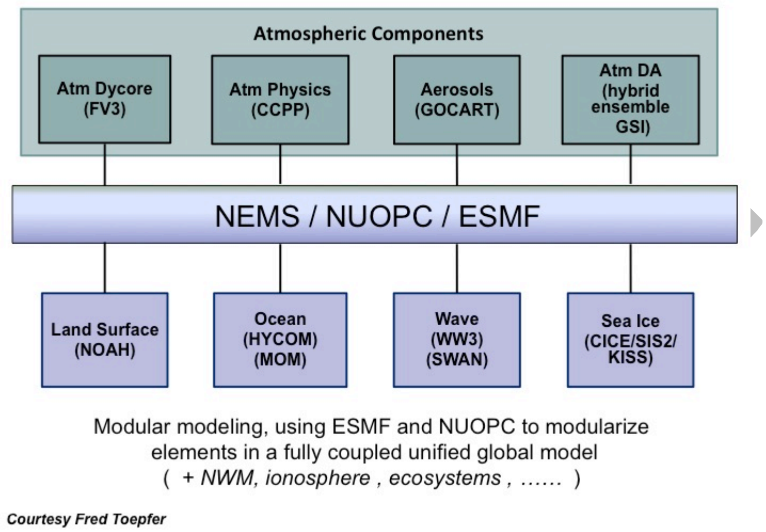


Figure 3: Modular NEMS design for coupled modeling

3.5 Component models

A key element needed to make the architecture of Figure 3 successful is to limit the number of models used for subcomponents, i.e., to use a unified approach per subcomponent. This is consistent with the NOAA Unified Modeling strategy as outlined by the NUMFT (NUMTF, 2016).

3.5.1 Weather

The global atmospheric models have traditionally been unified to a high degree around the Global Spectral Model (GSM), with a single physics package identified as the "GFS physics". The Climate Forecast System (CFS) and Global Ensemble Forecast System (GEFS) traditionally have been based on older versions of the GFS, and the main development has been focused on the high-resolution deterministic GFS model. As part of the NGGPS project, a new dynamic core has been selected to replace the spectral core of the GSM (Ji, et. al., 2016). The new core will be adopted from the GFDL FV3 model (Putman and Lin 2007; Harris and Lin 2013; Harris and Lin 2014; Harris, Lin, and Tu

2016). In the new PSN the following changes compared to the present PSN will be implemented with respect to global modeling:

- Full integration in the unified architecture (NEMS).
- One software package with three main applications (CGS, OGS, WGS)
- Parallel development of all applications (CGS, OGS, WGS), rather than "trickle down" approach from shorter to longer time scales.
- Separation of the dynamic core and the physics in the underlying architecture.

The present mesoscale modeling effort is not well unified, using four different models (WRF-ARW, NMM-B, HWRF, and GFDL hurricane), and a plethora of physics approaches in the SREF. Ideally the FV3 core will become the core for the RRGS and WoFGS regional application too, unifying all atmospheric models on a single dynamic core.

As observed by UMAC, it is essential to rapidly move to a unified Convection Allowing Model (CAM) approach for the RRGS ad WoFGS. This will require a short term CAM approach focused on a single CAM model (tentatively WRF-ARW), with a long-term transition to FV3, if this core proves suitable for CAM application (as expected but not yet proven).

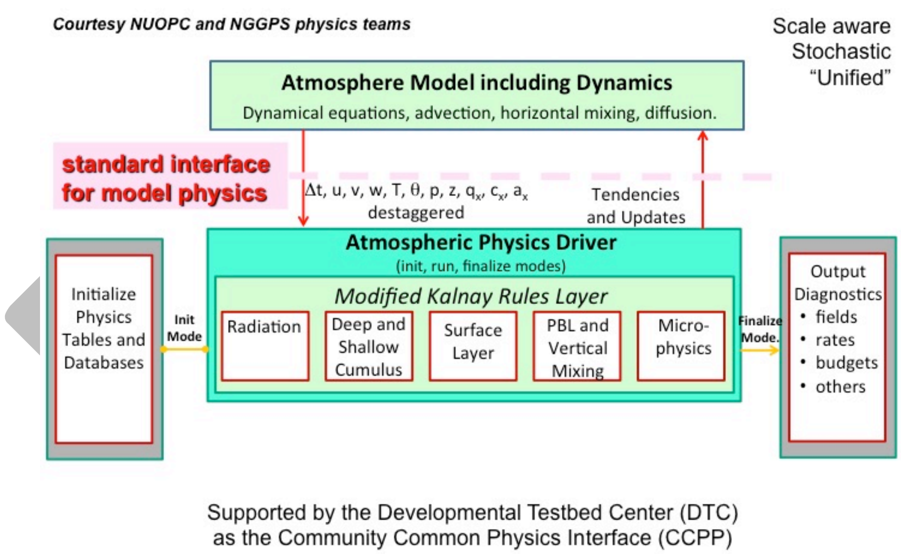


Figure 4: NUOPC Interoperable Physics Driver (IPD)

To facilitate both development and unification of physics packages, the dynamic core and physics are modularly separated in Figure 3. The NGGPS physics team in collaboration with NUOPC has developed an initial modular physics approach (Figure 4).

The success of the modular physics approach will depend on its unification. To be avoided are the large number of physics approaches presently used in the PSN, or the unbridled proliferation of physics approaches presently available in WRF. Whereas diversity enables scientific research, unbridled diversity has stunted true progress in modeling [add Cliff Mass reference NWP, Chicago 2015].

A short term transition to a unified physics approach applies the IPD / CCPP initially (less than 5 years) to a small number of successful operational physics packages (selected from, e.g., GFS, HRRR, NMMB, HWRF) while in the long term (5-10 years) moving to the most optimal unification across scales, utilizing both scale awareness and stochasticity. This will require a well-defined and strong governance approach with respect to developing physics approaches.

3.5.2 Other subcomponents

Figure 3 identifies additional models for environmental subcomponents as presently used in the PSN. In general, a reasonably unified approach is used for these subcomponents. Unified modeling as defined by the NUMTF does not imply unitary modeling (one model as a goal), but using the smallest number of models that makes scientific and economical sense. For instance, for oceans the Hybrid Coordinate Ocean Model (HYCOM) and the Modular Ocean Model (MOM) are used side-by-side, as they have been identified as more appropriate for weather and climate time scales, respectively.

Strategically, a unified approach for subcomponent models will continue for the next 5-10 years, but focal models for individual subcomponents may change, for instance:

- It is not clear if GOCART will have long-term support from its main developer (NASA), and in the community, WRF-Chem is becoming more popular, but has been used regionally only.
- Results from an October 2016 workshop with participants from NOAA, DoD and academia, suggest that the HYCOM and MOM community efforts might be combined in a single MOM6 approach.
- Several recent workshops on sea ice modeling have resulted in the development of a consortium to further develop the LANL CICE ice model as a true community model, and to explore if CICE, SIS2 and KISS elements can be included in a single community modeling framework.
- NOS is working with the community on focusing coastal ocean applications on a smaller set of models.

- SWPC is working with academia on community modeling efforts for space weather applications.

3.5.3 Data Assimilation

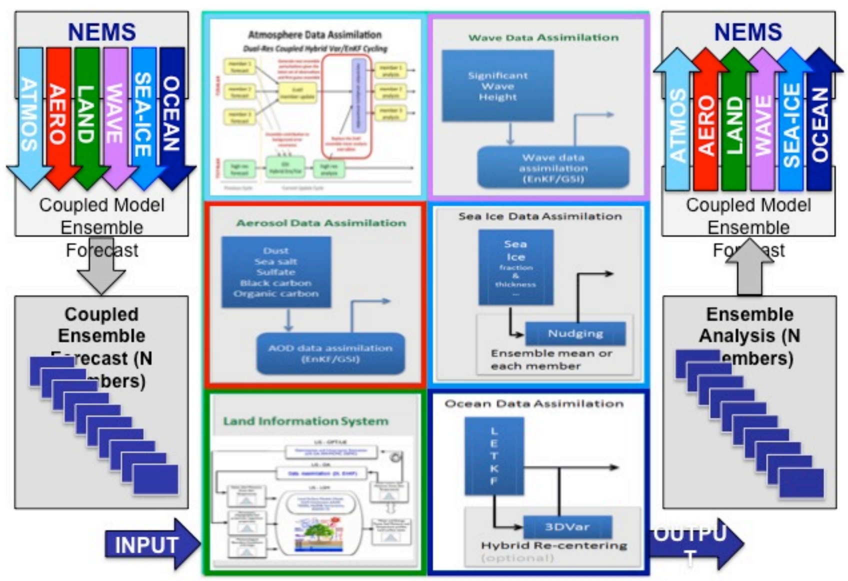
Data assimilation for the (global) atmosphere is specifically mentioned in Figure 3. Global atmospheric data assimilation (Global Data Assimilation System, GDAS) has transitioned rapidly to a hybrid ensemble 4D variational (4DVAR) approach, built around the Gridpoint Statistical Interpolation (GSI) software. A traditional 4D approach relies on adjoints of the model for which the DA is applied. The ensemble hybrid approach does not require an adjoint, but extracts the needed information from the ensemble. This makes the ensemble hybrid approach up to an order of magnitude cheaper in compute costs, and eliminates the need for developing and maintaining adjoints of models (roughly half the cost in human resources). This approach therefore represents a balance between economy and accuracy, and is expected to remain the mainstay approach for DA in the period covered by this strategic plan. Recently, the DTC has started to support this approach to the community, including cheaper 3DVAR approaches, and the GSI software is used by partners such as NASA.

Two projects with strategic importance are underway, and will shape the DA efforts for the next 5-10 years. The first is the Joint Effort for Data assimilation Integration (JEDI) of the Joint Center for Satellite Assimilation (JCSDA), which aims to provide a community environment for data assimilation. The second is a re-factoring of the GSI code, which is closely linked to JEDI. A key strategic goal for the simplification and unification of the PSN is to align the PSN with JEDI and vise versa, and to use these projects to apply a 4DVAR DA approach to all subcomponents of a full environmental modeling system.

A second strategic goal is to move to coupled DA. Generally, several levels of coupling in DA can be identified.

0. Uncoupled DA (present GDAS approach).
1. Weakly coupled
    a. Through first guesses from coupled models, but with independent DA per subsystem (present CFS approach).
    b. Through first guesses from coupled models, and in iteration loops in 4DVAR, but with independent DA per subsystems (in preparation at ECMWF).
2. Stronger coupled by addressing cross-correlations of errors between subsystems, but with independent DA per subsystems.
3. Fully coupled DA, including coupled (simultaneous) assimilation in all subsystems.

Coupled DA at level 1.a has proven its value in the CFSRR (Saha et al. 2010) and is similar to the coupled DA approach targeted by ECMWF (1.b). Level 2 represent the cutting edge of coupled DA, and a potential layout for such a system with six subcomponents is illustrated in Figure 5. Considering the lack of maturity of such an approach, the strategic goal for the PSN in the next 5-10 year should be to move toward such a coupled DA system, but without a strong commitment for implementation. Similarly, coupling at level 3 has not been tried at any level yet, and should be considered out of strategic scope in the next 5-10 years.



Courtesy Suru Saha

Figure 5: Potential prototype layout for a more coupled data assimilation approach using existing DA approaches for subcomponents (pre-JEDI)

3.6 Full Unification

Sections 3.2 through 3.5 deal with traditional guidance system in the PSN. Full unification of the PSN requires additional unification of functional areas that are shared across modeling systems.

3.6.1 Unifying data processing

Most components of the PSN depend critically on input from observations. For a truly unified PSN, it is critical that data ingest and quality control is done centrally, and not individually for either observation systems, or for modeling components. Similarly, mixing of data ingest with generation of specialized products (e.g., MODIS) needs to be avoided.

Similarly, postprocessing should be unified across modeling systems. This approach has been started with the establishment of the Unified Post Processor (UPP). The unified approach to post-processing needs to be expanded to all postprocessing, including use of RRs and community-based software. Common file formats and software that is extensible and shareable to enable collaboration are needed to support the advancement of the development and implementation of statistically post-processed products derived from the suite of operational models. MDL leads the effort to develop the suite of statistically post-processed guidance providing calibrated products in the form of Model Output Statistics (MOS), specialized aviation products known as the Localized Aviation MOS Program (LAMP), and the National Blend of Models.

3.6.2 Validation and Verification

A special case of data processing is model validation and verification (VV). Unification of VV within the PSN is sensible from a business perspective. Unification needs to address both standard metrics, and scorecards. The latter are critical because of the increasing complexity of (competing) requirements, and the reality that model upgrades provide incremental improvements, where not all metrics will be improved upon with any implementation.

More important is to unify VV between operations and research. Using unified VV is one of the key habits needed for operations to adopt test results from the research community without the need to redo much of the testing. Hence, unified VV will accelerate T2O, which is a high-level goal of NOAA [add NOA reference].

EMC has started to move its VV to the Model Evaluation Tool (MET) of NCAR. This requires a close collaboration between NCAR and the NWS, because unification of VV at the NS requires that MET includes all present VV techniques and tools as used for the PSN. Conversely, the PSN benefits from new validation techniques already available in MET, such as object oriented validation metrics (MODE, Method for Object-Based Diagnostics Evaluation). For true unification, a long-term goal is to add key parameters of other environmental subcomponents to MET.

3.6.3 Access to results

Binary model results from the PSN can be assessed in a unified way through sources such as "prodftp". However, data formats mandated by the World Meteorological Organization (WMO) such as BUFR and GRIB are not self-contained with respect to its metadata, and are therefore not fully discoverable on the world wide web. NOAA has partially moved into more modern data dissemination method with the development of the NOAA National Operational Model Archive & Distribution System (NOMADS), which uses OPeNDAP and THREDDS protocols for easier data access, and which includes some datasets in the fully discoverable NetCDF or HDF formats.

Many users on PSN products access data in graphical form from web sites. NCO's Models Analysis and Guidance website (MAG, http://mag.ncep.noaa.gov) attempts to provide a one-stop-shop, but presents only a small fraction of the PSN data. This web site is augmented with a plethora of disparate web sites, that are hard or impossible to discover. A unified PSN needs to be presented to its users in modern, one-stop web site, linked up to a one-stop data distribution channel.

Whereas these data access considerations could be considered outside he core functionality of the PSN, they are essential for public access to the PSN products, and therefore should be considered as part of an integrated SP and Roadmap.

4 End State

The previous section present basic elements of the Unified PSN in terms of forecast ranges of key element of the PSN, but does not address other details of their implementations. By nature, the details of the implementation are the subject of the SIP, because they critically depend on available resources. However, a tentative more detailed layout of the "End State" after 5 to 10 years is also essential for this SP to address the feasibility with respect to required compute resources. A detailed review of the key modeling elements of the Unified PSN is presented in Sections C.2 through C.7 of Appendix C, and is summarized in Table 2.

Table 2: Tentative End-State for key elements of the PSN in 5-10 years

Element	Cadence	Range	Resol.	Ens.	Update	RR
CGS	7 d	9-15 mo	50 km (g)	28	4 y	1979-present
OGS	24 h	35-45 d	35 km (g)	31	2 y	20-25 y
WGS	6 h	7-10 d	13 km (g)	26	1 y	3 y
RRGS	1 h 6-12 h 6-12 h	18 h 30 h 60 h	3 km (r)	26	1 y	TBD
WoFGS	5-15 min	2-4h	1 km (r)	26	1 y	TBD
Analyses						
Trad.	6-24 h	---	Var. (g)	---	6 mo	---
RUA	15 min	---	TBD (r)	---	6 mo	---

(g) Global
(r) regional
Red: uncharted territory

Items in red in Table 2 cannot be established accurately due to a lack of scientific evidence / established requirements. Note that the table does not address vertical resolution and number of levels. The Unified PSN should use the same vertical resolution for all Guidance Systems (with the exception of Space Weather), and should be increased to typically 100-150 levels to catch up with common practice in leading operational centers.

The cadence and forecast range in this table is mostly taken from Table 1, with the exception of the data for the RRGS. The hourly forecast for this range is 2-4 times per day extended to 30 h, and 2-4 times per day to 60h to cover all present PSN 3 km resolution guidance products (and their associated requirements). For the analyses, a distinction is made between the traditional global analyses such as Sea Surface Temperature (SST) and ice products, and the future regional Rapid Update Analysis (RUA) products.

The resolutions for all five Guidance Systems are fairly conservative for a 5-10 year outlook, representing the midpoint of this period. Furthermore, conservative resolution increases enable transition to full ensembles at the same spatial scales, as discussed in Section 3.3. Other environmental sub-components are not discussed in detail here, but their resolutions should be in balance with those of the weather components, and are addressed in the resources estimates provided below.

The ensemble sizes of the CGS and WGS represent a modest increase over the present ensemble sizes of the CFS and GEFS, respectively. The ensemble size of the WGS represents the largest ensemble size of the present systems it absorbs (i.e., the 26 member SREF ensemble). Ensembles sizes for the RRGS and WoFGS represent uncharted territory, and are based on the WGS ensemble size, and are likely to change as evidence for required CAM ensemble sizes develops.

The RR size for the CFS is as long as the satellite data record allows for, starting in 1979. For the OFS, it is determined mostly by requirements for hydrologic forecasts, and for the WGS, it is a much shorter period, so that the observational data used are representative for the present state of the observation system. This reflects that for the longer time scales (CGS, OGS), long RRs are essential for calibration of products and IDSS, and that for shorter forecasts initial conditions, and hence representativeness of data sources, is critical.

With the tentative layout of the key elements of the Unified PSN as summarized in Table 2, it is possible to estimate the computational cost of each element. This has been done by [add reference to whitepaper and spreadsheet], and is summarized in Table 3. The need for compute resources in PFlop are based on extending the present models run on the Weather and Climate Operational Supercomputing System (WCOSS) for configurations outlined in Table 2. They include costs of coupling and DA, and represent raw compute needs, and not the associated peak performance of the computer. As a reference the peak performance of the operational half of the WCOSS is approximately 2.8 PFlop.

Table 3: Compute cost estimates for PSN elements

	CGS	OGS	WGS	RRGS	WoFGS
PFlop	0.19	0.33	4.98	9.17	89.1[a] 8.91[b]
Fraction [c]	1.3%	2.2%	34%	63%	---

[a] Assuming same spatial coverage as RRGS
[b] Assuming 10% of spatial coverage as RRGS
[c] State before implementation of WoFGS

Table 3 shows that the CGS through RRGS all require resources that will tentatively fit on future operational computers, if compute capacity keeps up with Moore's law. The WoFGS if applied uniformly over the RRGS domain (option [a]) does not. If, however, the WoFGS is designed as relocatable nest covering only a fraction of the RRGS domain (option [b]), its implementation is likely feasible at the end of the period considered here. This implies that strategically, the WoFGS needs to be designed as a (set of) relocatable telescoping nest(s) in the RRGS, leveraging technology that has been used for the hurricane models. The RUA element is not included in the estimates, but is likely to represent a sub-set of the cost of the DA part of the RRGS. The bottom line in Table 3 shows the corresponding distribution of compute resources. Considering that historically, half the compute resources have been used for global applications, this identifying a shift toward resource allocation to CAM modeling for IDSS, consistent with requirement-based resource allocation.

Using estimates presented in Table 3, computer resources needed for the full Unified PSN can be estimated, and are presented in Table 4. Table 4 accounts for PSN elements other that the elements represented in Table 3 (e.g., the NWM) and accounts for the fact that only a fraction of peak performance can be used for sustained computing. "These values are based on current application performance and assume no performance improvements in the models' software. PSN models may not be able to leverage anticipated performance improvements in future HPC architectures without a significant code revision. Even so, code revision for improved performance will need to be assessed against code portability.

Table 4: Total compute needs in peak PFLOP for NOAA for full support of PSN

Ops	Backup	T2O	R&D	RR	Total
37	37	73	245	28	419

In Table 4 "**ops**" represents the operational supercomputer and "**backup**" the full operational backup as mandated by the Department of Homeland Security (Department of Homeland Security, Federal Continuity Directive 1: Federal Executive Branch National Continuity Program and Requirements, Annex G, October 2012). To fully support "**ops**", Transition to Operations (T2O) requires 3 times the compute resources of the operational machine, of which "**backup**" provides 1 factor and the "**T2O**" column represent the remaining 2 factors. Additional columns in Table 4 represent Research and Development ("**R&D**") preparatory to T2O, and the emerging need for dedicated resources for the RR requirements ("**RR**").

Table 4 provides a unique holistic view of compute needs for NOAA with respect to the PSN. Note that it is essential to balance these compute needs with sufficient storage (real-time and archiving) and bandwidth to move the resulting data. It is also imperative to address the different requirements for system for and reliability for the compute resources in Table 4, and that, depending on the run cadence, the CGS might not need to be run on the most reliable (and most expensive) computer.

5 Vetting and Approval

Appendices

Appendix A Coupled Environmental Modeling

The PSN of Figure 1 contains many other products, all of which are mandated products for the NWS. The following product types are part of the present production suite.

Land / Hydro: Land models are typically integrated in weather models, but are also used as stand-alone products. [Add text/references for mandate for doing this]

Ocean / Coast: NOS has traditionally provided coastal ocean products, directed by the Organic Act of February 10, 1807 founding the Survey of the Coasts, the Coast and Geodetic Survey Act of August 6, 1947, and the Hydrographic Services Improvement Act (HSIA) of 1998. Short term ocean forecasts became an official part of the PSN after a recommendation of the Science Advisory Board (SAB) on ocean modeling, and the NOAA Administrator's subsequent response (SAB, 2004, 2005). NCEP's Ocean Prediction Center (OPC) and National Hurricane Center (NHC) rely on short-term ocean surface and mixed layer products [provide mandate references]. NCEP's Climate Prediction Center (CPC) relies heavily on ocean models for seasonal outlooks products [provide mandate references].

Ice: [add paragraph with references to mandates]

Waves: The Safety Of Life At Sea (SOLAS) conference in 1974 created a mandate for weather services with marine responsibilities to address ocean waves as part of marine weather (SOLAS, 1974).

Aerosols: [add paragraph with references to mandates]

Space Weather: [add paragraph with references to mandates]

Additionally, NOAA is starting operational ecosystems products in response to the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998. . Presently, these products are downstream products produced by postprocessing marine model output. In the future, some of these models, particularly ecosystems processes associated with ocean color, may become part of an integrated operational environmental modeling system [add reference to EMC/MMAB whitepaper?].

Table 5 identifies which environmental subsystems with are already part of the PSN (Y in the Table), or which represent unmet requirements (R in the Table). Furthermore, with respect to coupling, literature shows benefits for some component models not yet in the PSN (S in the Table).

Table 5: Non-weather environmental subsystems in PSN.

Subsystem	Year	Month	Week	Day	Hour
Land / Hydro	Y	Y	Y	Y	?
Ocean / Coast	Y	Y	Y/R	S/R	?
Ice	Y	Y	S	?	?
Waves	S	Y	Y	Y	?
Aerosols	S	S	Y	Y	?
Space Weather	?	?	Y	?	?

Y*: Present product.* S*: Science benefit for coupling.* R*: Unmet requirement.* ?*: TBD*

For the subsystems that are already in the PSN or those that should be there (Y and R in Table 5), there are benefits for the initial creation of a one-way coupled system, that is, information in the coupling flowing only from the atmospheric component to the traditional downstream component. There are four benefits for such a one-way coupled approach:

1. It generally increases the time resolution of the forcing for the downstream models while reducing I/O needed to force models.
2. It creates a more integrated test environment for holistic evaluation of model upgrades throughout the PSN. Presently, impacts on downstream models are not always assessed adequately in an implementation.
3. It reduces the number of implementations.
4. It creates an environment for investigating benefits of two-way coupling, and it enables two-way coupling if science proves there is a benefit.

For many of the environmental subsystems (Y in Table 5), the costs of coupling will be minimal, as the resources needed to run the sub-components are already expended in the PSN. For coupled subsystems representing unmet requirements, of with science benefits which are not yet represented in the PSN (R and S in Table 5), adding the new environmental subsystem to the PSN will increase computational costs as they represent new products from new model applications.

Of course, there are also negative aspects to coupling, for instance

1. Individual implementations of coupled systems are more complex than those of traditionally isolated subsystems.
2. There will be less flexibility in tailoring products of subsystems, particularly with respect to run-cadence and forecast range.

3. Development of subsystems needs to be much more rigorously tested in a coupled environment, instead of in a “stand-alone” environment (avoiding unintended consequences of coupling).

In particular with respect to the last point, it is essential to use a modeling architecture that allows for effective development of coupled systems, as well as a capability to use different coupling strategies in different applications of a single unified modeling system (see Section 0).

Appendix B Odd elements in the PSN

When reviewing the present PSN, several products and their applications do not fit seamlessly in the overarching PSN layout of Figure 2.

Hurricane models: The present HWRF and HNMMB hurricane models utilize relocatable telescoping nests to provide the best balance between accuracy of intensity guidance with economy of computation (Zhang et al., 2016, Goldberg et al., 2015, Trahan et al., 2013). [add references]. Tentatively, these individual telescoping nests for individual tropical storms could be integrated in a global high-resolution model, as is depicted in Figure 2 with the overlapping WGS and Hurricane Nest boxes. Such an approach is under development as part of the Hurricane Forecast Improvement Project (HFIP) and NGGPS (Gopalakrishnan et al., 2016, Gall et al., 2014).

Space Weather: Space Weather applications are a relatively recent requirement from the Space Weather Prediction Center (SWPC) [add references]. The atmospheric components of such models consider model tops well into the ionosphere, where prevalent temperatures and wind speeds result in either very small time steps, or much lower horizontal resolutions than attainable in conventional weather models with lower model tops [add references]. Combined with the need for a faster model cadence desired for space weather applications [add references]. It is prudent to treat the space weather applications for the foreseeable future as a separate application, sharing the weather models with the other global guidance systems in Figure 2 Whereas there may be benefits for integrating space weather applications more fully with the more traditional global applications in Figure 2, this should be treated as a potential unification of opportunity, but not as a fundamental goal of the unification of the PSN in the next 10 years. The whole atmosphere / space weather box in Figure 2 is therefore a separate, non-overlapping application.

National Water Model: The National Water Model (NWM), based on the WRF-Hydro hydrologic modeling framework, is a recent addition to the PSN, and has been designed to be compatible with the existing PSN, and with the developing unification of the PSN) (Cosgrove et al., 2016; Givati et al., 2016; Gochis et al., 2015; Lin et al., 2016; Senatore et al., 2015; Xiang et al., 2016; Yucel et al., 2015). The first Initial Operational Capability (IOC) of the NWM was implemented in August 2016. The NWM is inherently regional, but is intended to be driven by many global products in the PSN. This makes the initial implementation of the NWM naturally a downstream rather than integrated and coupled element of the PSN. A possible exception is the integration of the relevant parts of the NWM in the RRGS. Considering the developmental status of the NWM, this should be considered a unification of opportunity rather than a fundamental goal in this strategic plan. Even with the downstream nature of this model, linkages with NOS coastal models, NWS and NOS storm surge models, and the NWPS with respect to coastal inundation will require continuous coordination to avoid duplication of products and inconsistent products in the PSN. Furthermore, linkage of land model errors with limited hydrological capabilities in present weather models) [add references to CAWCR, 2015]. Make the full integration of the NWS in coupled PSN a long-term goal.

Nearshore Wave Prediction System: The Nearshore Wave Prediction System (NWPS) represents a unique on-demand model for guidance for high-impact coastal issues such as waves, inundation (still to be implemented) and rip currents) [add references]. This application is / has to be integrated with the PSN through use of products and shared software. While developing a unified PSN, overlap between NWPS, NWM, NOS coastal models and the NOAA storm surge roadmap effort will need to be addressed continuously. Due to its on-demand nature, it is represented as a separate box in Figure 2.

Coastal models: The coastal and port models of NOS similarly have a highly localized nature. Until the initial unification of the PSN is achieved, it is prudent to keep such models as separate downstream models in the PSN, and treat these model as targets of opportunity for coupling / unification where appropriate and feasible.

On-demand Dispersion models: The Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT), developed by NOAA's Air Resources Laboratory, is one of the most widely used models for atmospheric trajectory and dispersion calculations. HYSPLIT is used at NCEP for on-demand response for radionuclide and hazardous material release, volcanic ash as well as for smoke originated from and wind-blown dust, Stein, et al. (2015).

NDFD driven downstream models: Starting with the Great Lakes wave models, some traditional "downstream" models in the PSN are alternatively driven by forecaster-produced National Digital Forecast Database (NDFD) winds (Alves et al., 2014). The benefit of such an approach is that downstream models have the maximum consistency with the official weather forecast, and are potentially model accurate. However, the approach becomes more cumbersome in an inherently coupled PSN, and is leading to a proliferation of specialized applications in the PSN. It is not clear what the position of such models in unified coupled PSN will be.

Appendix C PSN Core Elements

C.1. Introduction

Sections C.2 through C.7 describe the six main elements of the new layout of the PSN as outlined in Figure 2. Discussed are the tentative layout, the present status (including mature science finding that drive near-term expansions), and key science questions that need to be addressed in order to implement the element. Section C.8 discussed Reforecasts and Reanalyses (RRs), and Section C.9 discusses combined ensembles.

C.2. Year range (CGS, seasonal climate)

Tentative layout: A fully coupled atmosphere, land, ocean, wave, ice and aerosol ensemble model with a typical resolution of approximately 50 km and a forecast range of 9 months, or up to 15 months if evidence proves the value of the extension in forecast range, with an extended ensemble size updating weekly. The DA system will also move to a more strongly coupled approach. The targeted update cycle for the CGS is four years.

Present status: in the present PSN, the Climate Forecast System (CFS) provides this element. In terms of applications, this part of the PSN is already unified. The CFS typically uses previous generation technology from the Global Forecast System (GFS) and the Global ensemble Forecast System (GEFS). In the PSN layout of **Error! Reference source not found.**, development of the various global applications will become a more parallel approach, with the CGS tentatively leading the way with respect to advanced coupling techniques. Mature science indicates that wave coupling needs to be added to improve ocean mixed layer prediction though Langmuir mixing) [add references].

Key science questions / issues: The following key science questions need to be addressed to guide the development of the CGS:

- *Predictability*; which products have a societal benefit, and scientifically proven value with respect to predictability. The present CFS historically focused on ENSO prediction.
- *Advanced coupling*; the present CFS couples atmosphere, land, ocean and ice. A plethora of potential benefits for more detailed coupling can be found in literature, and need to be assessed in the operational environment, both with respect to the forecast model and with respect to DA.
- *Physics*; include features of physics packages presently used in the mesoscale models in global PSN elements such as the CGS. The benefits to be addressed are

improved forecasts in general, and better server weather outlook products in particular (boundary layer representation, CAPE, Lifted Index, etc.). Additional attention needs to be given to stochastic physics approaches, enabling (together with coupling) realistic spreads of ensemble products.

- *DA*: Quantify the impact of stronger coupled DA.
- *DA*: Does the CGS need it's own DA system, or will it use the OGS or WGS DA system.
- *Optimum ensemble sizes*. For operations, ensemble sizes have been determined more by available resources than by scientific evidence.

Implementation issues: The new CGS represents a subset of the present CFS products (9 month runs only), and as such is trivial to implement. Issues to be addressed with users are reducing the update rate of the products from daily in the CFS to weekly in the CGS. Technical issues to be addressed are where to run this system (i.e., does this need to run on the operational computer if the update cycle is weekly?), and how to deal with the substantial RRs requirements.

C.3. Month range (OGS, weeks 3 and 4)

Tentative layout: A fully coupled atmosphere, land, ocean, wave, ice (and possibly aerosol) model with a typical resolution of approximately 35 km and a forecast range of 35 to 45 days, with an extended ensemble size updating daily. The DA system will also move to a more strongly coupled approach. The targeted update cycle for the OGS is two years.

Present status: in the present PSN, the 45-day runs of the CFS provide this element. In the new PSN layout, targeting a coupled extended GEFS to become the starting point for the OFS is preferred as the CGS and OGS target different model resolutions. The present Global Wave Ensemble System (GWES) will naturally be absorbed in the OGS, initially in a one-way coupled approach, enabling more strongly coupled future approaches. Ocean and ice components can be taken from the present CFS, but do not yet exist in the extended GEFS environment. Evidence of predictability in this forecast range is scant, with a focus on MJO predictability with coupled models. (Saha et al, 2014). Note that the Office of Science and Technology Policy (OSTP) in [insert month/year w/reference] mandated this product range, and its implementation is therefore less evidence-driven than the implementation of most PSN elements.

Key science questions / issues: The key science questions that need to be addressed for the development of the OGS are similar to those posed for the CFS.

- *Predictability*; Some predictability exists in this forecast range with respect to MJO as mentioned above. For key forecast parameters addressed by CPC (US temperature and precipitation outlooks for weeks 3 and 4) no present predictability is obtained from models. To get to predictability of these parameters is a major science issue.

- *Advanced coupling*; see comments on CGS. Coupled approaches are essential for predictability (e.g., MJO), but maturity of coupled modeling for these time scales may require an IOC with limited coupling. Note that coupling at short forecast ranges might require a hybrid approach where coupling is introduced slowly as the forecast proceeds) [add references]..
- *Physics*; see comments on CGS.
- *DA*: Quantify the impact of stronger coupled DA.
- *DA*: Does the OGS need it's own DA system, or will it use the WGS DA system.
- *Optimum ensemble sizes*; see comments on CGS.

Implementation issues: The OFS of the unified PSN will be filled by extending the GEFS, while replacing the 45 day runs of the present CFS, and as such is relatively trivial to implement. Technical implementation issues to be addressed are to phase in coupling rapidly but reasonably, and how to deal with substantial RR requirements.

C.4. Week range (WGS, actionable weather)

Tentative layout: The WFS will consist of a global 10-13 km resolution ensemble weather model with 21-26 members running a 5-8 day forecast every 6 hours. All other environmental subsystems are at least one-way coupled, and two-way coupled where the scientific benefit is proven. The WFS will become the focal point for global DA efforts. The targeted update cycle for the WFS is annually.

Present status: There is presently no global ensemble at this resolution and forecast range in the PSN. However, there are many weather components in the PSN at this spatial scales and forecast ranges that will be absorbed in the WFS. These are the deterministic Global Forecast System (GFS), deterministic North American Mesoscale (NAM) parent model, deterministic RAP, and the regional Short Range Ensemble Forecast (SREF) systems, as well as elements of the nested HWRF model. All other environmental subsystems already have components in the PSN, with land models embedded in the weather models, the global Real Time Ocean Forecast System (RTOFS-Global, run daily), the global multi-scale wave model, and an ice model embedded in RTOFS-Global. Aerosols are coupled within the NEMS Global Aerosol Capability (NGAC) with dust predictions provided since 2012 and other aerosols (smoke, sulfates, sea salt) experimentally since 2016 (Lu, et al., 2016). Regional ozone and fine particulate matter predictions are produced from the National Air Quality Forecast Capability, EPA Community Model for Air Quality (CMAQ, Lee, et al., 2016).

Key science questions / issues: The key science questions that need to be addressed for the development of the WGS are somewhat different from those that need to be addressed for the CGS and the OGS.

- *Ensemble design*; the WGS will consist of a single-core ensemble. At these space scales, it is not yet clear how to develop an ensemble with a reasonable spread. Sensible paths of research include stochastic physics and variability in boundary data obtained by the weather models from other environmental subcomponents. Note that the tentative ensemble size is taken from the SREF, but should be considered systematically.
- *Physics*; see comments on mesoscale physics features for CGS and OGS, and need for stochastic physics mentioned in the previous bullet. Another issue to be addressed at this scale is the need for scale-aware physics, particularly if unified physics are used throughout the PSN, and if the WGS eventually moves into “grey zone” spatial scales (see also Section 5).
- DA; is there a need / benefit for running DA at slower or faster cadences than 6h. Quantify the impact of coupled DA.
- How will space weather and hurricane science and engineering issues be addressed to possible merge these two applications with the WGS.

Implementation issues: The new WGS element of the PSN will replace many components of the present PSN. This will be complicated with respect to many aspects of the PSN, and will require a detailed transition plan.

- Users need to transitions from present products to equivalent products from the new WGS. Providing “look-alike” products should be avoided, or provided with limited shelf-life only, because such products have proliferated in the past, and even now represent a significant part of the products provided by the PSN
- The present models with 13km resolution have many downstream dependencies, for instance to provide input data for the NWPS and the High Resolution Rapid Refresh (HRRR) models. While the PSN transitions to its new layout, all these dependencies need to be address, either permanently, or for transition purposed only.

Whereas moving from deterministic individual environmental subcomponent to an at least one-way coupled approach is mostly cost-neutral, the introduction of a full ensemble approach is not. This is only partially offset by re-using resources no longer used by the SREF ensemble.

C.5. Day range (RRGS, rapid refresh regional)

Tentative layout: The RRGS will consist of a regional 3 km resolution ensemble weather model with approximately 20 members running an 18h forecast every hour. This creates a Convection Allowing Model (CAM) model ensemble. Two to four times per day, the forecast will be extended to 30h, and two to four times per day, the forecast range will be extended to 60h. This configuration covers all present deterministic mesoscale model products in the PSN, and was suggested by the NWS regional representatives. The RRGS will have its own regional data assimilation scheme, consistent with global DA, and will cover all areas for which the NWS presently has regional products and responsibilities (CONUS, Alaska, Hawaii, Guam, and Puerto Rico). One way coupling to waves, ice and circulation for the Great Lakes will be included, and will be expanded to two-way coupling in the time frame of this strategic plan. The latter is based on the clear benefit of such coupling for "Lake Effect Weather", as has been demonstrated operationally by Environment Canada for the Saint Laurence Seaway regional coupled model) [add references]. The targeted update cycle for the RRFS is annually.

Present status: Presently, the PSN only has deterministic components that are consistent with the envisioned RRGS, These are (i) the High Resolution Rapid Refresh (HRRR) model, running a 3km resolution18h CONUS WRF-ARW forecast every hour, (ii) the NAM nest, running a 3-6km resolution 60h NMMB forecast every 6h for CONUS, Alaska, Hawaii and Puerto Rico, (iii) the HighResWindow model, running a 3-4km resolution 48h NMMB and WRF-ARW forecast every 12h for CONUS, Alaska, Hawaii, Puerto Rico, and Guam, and finally (iv) the FireWXNest, running a 1.5km resolution 36h NMMB forecast every 6h for a placeable 500 km^2 grid. There is presently no ensemble at this scale yet, and the DA approach is significantly less advanced than for the global models with respect to the underlying approaches. Land models are embedded in the above weather models, lake circulation, waves and ice for models are run for the Great Lakes as part of the present PSN as downstream models. EMC, NOS and the Great Lakes Environmental Research Laboratory (GLERL) are presently developing a coupled circulation-wave-ice model, intended to replace the corresponding uncoupled subsystems in the PSN.

Key science questions / issues: The RRGS largely represents a new ensemble system with many science and engineering questions to be addressed.

- *Ensemble design*; see corresponding issued for WGS ensemble. For the RRGS, the selection of the dynamic core is additional issue. The new dycore selected for the UGCM needs to be tested for applicability of the RRGS scales. As this core is not yet available, the present research is most efficiently done with the WRF-ARW as is the foundation of the HRRR model.

- *Physics*; see corresponding issues for WGS physics.
- *DA*; DA at this resolution is innovative with respect to using radar data, but is in its infancy with respect to basic approaches as used. Approaches for global models, HRRR and NAM models need to me leveraged and merged, resulting in an ensemble hybrid 4DVAR approach. Much work needs to be done in this field, and uncertainty in the size of the ensembles needed for such a hybrid convection allowing DA approach make costs estimates somewhat uncertain.

Implementation issues: The RRGS aims to replace a set of deterministic CAM products with a full (new) ensemble set of products, as well as with a much more advanced DA approach. This implies a massive increase of required compute resources, tentatively 20 times the resources used by the present HRRR model. Where the RRFS combines a disparate set of previous models, the same transition issues will occur with respect to changing products as was discussed for the WGS. An implementation issue unique to the RGS is the need for unifying the dynamic core, either by going to a single meso scale model (WRF-ARW), or in adopting the new global FV3 dynamic core directly in the meso applications. Note that as long as the underlying model has not been selected, it is prudent to focus development on model-agnostic research topics.

C.6. Hour range (WoFGS, Warn on Forecast regional)

Tentative layout: 1 km resolution 5-15' cadence ensemble forecasts of 3-6 hours with a placeable and possibly moving nest (see Section 4), with initial and boundary conditions from the RRGS, and additional assimilation of in particular radar data.

Present status: N/A

Key science questions / issues: This system effectively has to be designed from the ground up, as a natural extension of the RRGS.

Implementation issues: Not to be considered until the end of the period addressed by this strategic plan due to maturity of science and technology, as well as required computer resources

C.7. Now range (analyses)

Tentative layout: traditional, usually global analyses such as the Real Time Global Sea Surface Temperature (RTGSST) and ice concentration analyses used as model input and for model validation, For the focus are of the NWS, the Rapidly Updated Analysis will provide a three-dimensional CAM resolution atmospheric analysis at time intervals as short as 5-15 min (i.e. analysis is perform as soon as new Doppler Radar observations are available).

Present status: RTGSST and ice products are produced once per day, and do not include diurnal information. The Real Time Mesoscale Analysis (RTMA) and UnRestricted Mesoscale Analysis (URMA) provide high-resolution regional (surface) analyses four times per day. [add notes on MODIS and other systems that provide analyses]

Key science questions / issues: The global, slow cadence products are well established. The RUA represents a new technology that is not yet in the PSN, with the following science and engineering question:

- Should the RTMA evolve into a RUA, or should the RUA be developed in parallel.
- The RUA will present unique engineering challenges due to the need for a very short latency to make a 15 min or faster update useful.
- There is a social science challenge associated with all analyses as forecaster want to see analyses that fit observations exactly, whereas scientists acknowledge unavoidable errors in both observations and analyses, and hence expect analyses ***not*** to represent data exactly.

Implementation issues: The RUA represents a new capability that will need to be resourced properly. A challenge for unifying the PSN is that systems like MODIS provide both data processing and analysis. In a Unified PSN, data processing and analyses should be separated, with the analyses products gathered into a single RUA (or unified global) approach.

C.8. Reforecast and reanalysis

Tentative layout: RRs are made for all key elements of the Unified PSN, with a focus on model calibration and correction for the longer time scale, and on model validation and interpretation for shorter time scales. For longer time scales, a distinction needs to be made for RRs for calibration, which can be done with relatively small RRS [add Hammill et all whitepaper reference], and reforecasts for IDSS support, which require much larger RRs [add reference to OHD work].

Present status: the CFS comes with a complete RR (Saha et al. 2010), and the GEFS has a "one-off" reforecast [add reference]. Other components have extensive retrospective testing, but this is presently done in a deterministic way, not as a RR ensemble.

Key science questions / issues: The RRs still largely represents a new element of the PSN with many science and engineering questions to be addressed.

- Should /can RRs be done in real time ("on the fly") or should they be completed off-line before implementation of .the corresponding element in the PSN.

- General ensemble generation with proper spread based on single core components with stochastic physics in the atmosphere and perturbed coupled NEMS components is preferable, but still need massive scientific development work/
- Presently IDSS reanalyses requirements are associated with brute force reanalyses, i.e., using a high and constant temporal sampling rate. Experience with other fields of sampling and optimization suggests that smart, dynamic sampling can massively reduce the size of ensembles. Initiating research into dynamic sampling for RRs is essential for economic feasibility.

Implementation issues: The RRs are not a traditional ***operational*** element of the real-time operational PSN. It should be run on dedicated compute resources, that can be significantly cheaper than the WCOSS and its successors, since the availability requires for RRs are much more lenient than for the conventional PSN. For the longer time scale forecasts, RRs are essential for model validation and correction, and the associated resources need to be planed rigorously to assure minimal and predictable impact on the implementation schedules. Due to their size, it may not be able to do IDSS reforecasts for every model upgrade. It is essential, however, to do smaller calibration RRs for each implementation.

C.9. Combined ensembles

Tentative layout: The present PSN includes multi-model ensembles build from contributions of different organizations, and blended model products. In the PSN, maintaining multi-model ensembles such as the SREF can only be justified from a business perspective if the scientific evidence does not support single-model ensembles. Multi-model ensembles where multiple organizations combine the single-model ensembles in a cross-organizational multi-model ensemble, however, do provide a viable long-term business model for high fidelity, large membership ensembles. The latter is particularly true if this approach is implemented with shared modular modeling components as is envisioned in the National ESPC.

Present status: The present PSN contain the North American Ensemble Forecast System (NAEFS) and the NCEP FNMOC Wave Ensemble System (NFWES). Both systems either have, or are intended to have contributions from NCEP, Navy and Environment Canada (operational) model. Since 2006, the NAEFS combines state of the art weather forecast tools, called ensemble forecasts, developed at the US National Weather Service (NWS) and the Meteorological Service of Canada (MSC). When combined, these tools (a) provide weather forecast guidance for the 1-14 day period that is of higher quality than the currently available operational guidance based on either of the two sets of tools separately; and (b) make a set of forecasts that are seamless across the national boundaries over North America, between Mexico and the US, and between the US and Canada. The National Blend of Models is developing a complete set of post-processed guidance for NDFD weather elements by leveraging evolving state of the science data assimilation analyses, ensemble systems and statistical post-processing techniques to remove bias, produce reliable probabilistic output and make the forecast guidance more useful.

Key science questions / issues: Design have, and optimal merging of multi-model ensembles.

Implementation issues: The existing ensembles represent a small commitment in CPU time as it represents post-processing only of existing model output, but does require a significant disk-space commitment, dedicated connectivity and bandwidth between collaborating organizations, and some human resources. With the focus of the NWS on reliable, timely and on-time delivery, reliable connectivity and delivery times from external contributors is and will be critical.

Appendix D References

Alves, J.-H. G. M., A. Chawla, H. L. Tolman, D. Schwab, G. Lang, and G. Mann, 2014: The Great Lakes wave forecast model at NCEP/NOAA: General features and future developments, *Weather and Forecasting*, pp. 1473-1497.

Carman, J., D. Eleuterio, T. Gallaudet, G. Geernaert, P. Harr, J. Kaye, D. McCarren, C. McLean, S. Sandgathe, F. Toepfer, and L. Uccellini, 0: The National Earth System Prediction Capability: Coordinating the Giant. *Bull. Amer. Meteor. Soc.,* **0**, doi: 10.1175/BAMS-D-16-0002.1.

Cosgrove, B., D. J. Gochis, E. Clark, Z. Cui, A. Dugger, G. Fall, X. Feng, M. A. Fresch, J. J. Gourley, S. Khan, D. Kitzmiller, H. Lee, Y. Liu, J. McCreight, A. Newman, A. Oubeidillah, L. Pan, C. Pham, F. Salas, K. Sampson, G. Sood, M. B. Smith, A. W. Wood, D. Yates, W. Yu, and Y. Zhang, 2016, Hydrologic Modeling at the National Water Center: Operational Implementation of the WRF-Hydro Model to support National Weather Service Hydrology. Paper presented at the American Meteorological Society Annual Meeting, New Orleans, LA.

Gall, R, F. Toepfer, F. Marks, and E. Rappapor, 2014:Hurricane Forecast Improvement Project Years Five to Ten Strategic Plan. HFIP Technical Report: HFIP2014-1.1.

Givati, A., D. Gochis, T. Rummler, H. Kunstmann, 2016: Comparing One-way and Two-way Coupled Hydrometeorological Forecasting Systems for Flood Forecasting in the Mediterranean Region. In press, Hydrology.

Gochis, D.J., W. Yu, D.N. Yates, 2015: The WRF-Hydro model technical description and user's guide version 3.0. NCAR Technical Document. 120 pages. Available online at: http://www.ral.ucar.edu/projects/wrf_hydro/.

Goldenberg, S. B., S. G. Gopalakrishnan, V. Tallapragada, T. Quirino, F. Marks, S. Trahan, X. Zhang, and R. Atlas, 2015: The 2012 triply-nested, high-resolution operational version of the hurricane weather research and forecasting System (HWRF): Track and intensity forecast verifications. Wea. Forecasting, 30(3):710-729, doi:10.1175/WAF-D-14-00098.1

Gopalakrishnan, S., F. Toepfer, R. Gall, F. Marks, E. N. Rappaport, V. Tallapragada, S. Forsythe-Newell, A. Aksoy, J. W. Bao, M. Bender, L. Bernardet, J. Cione, M. Biswas, J. Cangialosi, M. DeMaria, M.Morin, J. Doyle, J. L. Franklin, S. Goldenberg, George Halliwell, C. Holt, S. Jason, H. S. Kim, P. Kucera, N. Lett, P. McCaslin, A. Mehra, M. Mills, J. Moskaitis, A. Sergio, J. Sippel, S. Trahan, H. Tolman, R. Torn, X. Wang, J. Whitaker, D. A. Zelinsky, F. Zhang, X. Zhang, Z. Zhang, 2016: 2015 Hurricane Forecast Improvement Project R&D Activities Summary: Recent Results and Operational Implementation. HFIP Annual Report, HFIP2016-1.

Ji, M., R. Gall, R. Rood, J. Thuburn, M. Peng, V. Ramaswamy, K. Kelleher, H. Tolman, F. Toepfer, T. Schneider, I. Stajner, J. Whitaker, J. Michalakes, S-J. Lin, V. Tallapragada, S. Benjamin, J. Doyle, R. Mathur, S. Warren, S. Morris, 2016: Dynamical Core Evaluation Test Report for NOAA's Next Generation Global Prediction System (NGGPS), July, 2016. 93 pp[3]. Available from:

Lee. P., McQueen, J.T., Stajner, I., J. Huang, Li Pan, D. Tong, H-C Kim, Y. Tang , S. Kondragunta, M. Ruminski, S. Lu, E. Rogers, R. Saylor, P. Shafran, H-C Huang, J. Gorline, S. Upadhayay, and R. Artz, 2016: NAQFC developmental forecast guidance for fine particulate matter (PM2.5). Wea. Forec. (accepted) DOI:10.1175/WAF-D-15-0163.1

Lin, P., Z.-L. Yang, D.J. Gochis, W. Yu, D. R. Maidment, M.A. Somos-Valenzuela, C. David, 2016: Development and evaluation of a hybrid framework (WRF-Hydro-RAPID) for flash flood modeling: A case study for Hurricane Ike flooding in 2008. Submitted to Env. Modeling and Software, March, 2016.

Lu, C.-H., da Silva, A., Wang, J., Moorthi, S., Chin, M., Colarco, P., Tang, Y., Bhattacharjee, P. S., Chen, S.-P., Chuang, H.-Y., Juang, H.-M. H., McQueen, J., and Iredell, M.: The implementation of NEMS GFS Aerosol Component (NGAC) Version 1.0 for global dust forecasting at NOAA/NCEP, Geosci. Model Dev., 9, 1905-1919, doi:10.5194/gmd-9-1905-2016, 2016.

NRC Report, 2006: Completing the Forecast - Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts, The National Academic Press, 1-174

NUMTF, 2016: [add reference to NUMTF white paper]

Saha, S, et al., 2010: The NCEP Climate Forecast System Reanalysis, *Bulletin of the American Meteorological Society*, **91**, pp. 1,015-1,057.

Senatore, A., G. Mendicino, D. J. Gochis, W. Yu, D. N. Yates, and H. Kunstmann. (2015), Fully coupled atmosphere-hydrology simulations for the central Mediterranean: Impact of enhanced hydrological parameterization for short and long time scales, J. Adv. Model. Earth Syst., 07, doi:10.1002/2015MS000510.

SOLAS, 1974: [add reference]

Sandgathe, S., W. O'Connor, N. Lett, D. McCarren, and F. Toepfer, 2011: National Unified Operational Prediction Capability Initiative. *Bull. Amer. Meteor. Soc.,* **92**, 1347–1351, doi: 10.1175/2011BAMS3212.1.

[3] http://www.weather.gov/sti/stimodeling_nggps_implementation_atmdynamics

Stein, A., R. Draxler, G. Rolph, B. Stunder, M. Cohen, and F. Ngan, 2015: NOAA's HYSPLIT Atmospheric Transport and Dispersion Modeling System. *Bull. Amer. Meteor. Soc.,* **96**, 2059–2077, doi: 10.1175/BAMS-D-14-00110.1.

Theurich, G., C. DeLuca, T. Campbell, F. Liu, K. Saint, M. Vertenstein, J. Chen, R. Oehmke, J. Doyle, T. Whitcomb, A. Wallcraft, M. Iredell, T. Black, A. Da Silva, T. Clune, R. Ferraro, P. Li, M. Kelley, I. Aleinov, V. Balaji, N. Zadeh, R. Jacob, B. Kirtman, F. Giraldo, D. McCarren, S. Sandgathe, S. Peckham, and R. Dunlap, 2016: The Earth System Prediction Suite: Toward a Coordinated U.S. Modeling Capability. *Bull. Amer. Meteor. Soc.,* **97**, 1229–1247, doi: 10.1175/BAMS-D-14-00164.1.

Toepfer, F. et. al., 2014: R2O Initiative: Next Generation Global Prediction System (NGGPS) Implementation Plan, Ver. 1.0, October 10, 2014. 51 pp.[4]

Trahan, S., Y. Kwon, Q. Liu, X. Zhang, H-Y Chuang, D. Zelinsky, G.Thompson, S. Bao, L. Bernardet, V.Tallapragada, and B. Ferrier, 2013: Improved Telescopic Nesting and its Effects on Hurricane Forecasting. Tropical Cyclone Research Forum, 67 th Interdepartmental Hurricane Conference, 5–8 March, 2013, NOAA Center for Weather and Climate Prediction, College Park, MD.

UCACN, 2009: 2009 NCEP center reviews[5].

UCACN, 2011-2015: Annual reports[6].

UMAC, 2015: Report of the UCACN Model Advisory Committee, 72 pp.[7]

Xiang, T., Vivoni, E.R. and Gochis, D.J. 2016. On the Diurnal Cycle of Surface Energy Fluxes in the North American Monsoon Region using the WRF-Hydro Modeling System. Submitted to J. Hydrometeorology, Mar. 2016.

Yucel, I., Onen, A., Yilmaz, K. and Gochis, D. 2015. Calibration and evaluation of a flood forecasting system: Utility of numerical weather prediction model, data assimilation and satellite-based rainfall. J. Hydrol. 523, 49 – 66.

Zhang, X., S. G. Gopalakrishnan, S. Trahan, T. Quirino, Q. Liu, Z. Zhang, G. Alaka, and V. Tallapragada, 2016: Representing Multiple Scales in the Hurricane Weather Research and Forecasting Modeling System: Design of Multiple Sets of Movable Multi-Level Nesting and the Basin-scale HWRF Forecast Application. Wea. Forecasting, doi: 10.1175/WAF-D-16-0087.1

[4] http://www.nws.noaa.gov/ost/nggps/NGGPS Implementation Plan v1.0.pdf
[5] https://www.vsp.ucar.edu/ucacn/final-reports
[6] https://www.vsp.ucar.edu/ucacn/final-reports
[7] http://www.ncep.noaa.gov/director/ucar_reports/ucacn_20151207/UMAC_Final_Report_20151207-v14.pdf

Zhou, X. Y. Zhu, D. Hou, Y. Luo, J. Peng and D. Wobus, 2016: "The NCEP Global Ensemble Forecast System with the EnKF Initialization" Submitted to Monthly Weather Review (Jan. 2016)

Appendix E Contributors

The following is an alphabetic list of contributors to this strategic plan.

Burke, Patrick	Oceanography Division, COOPS. NOS
Carman, Jessie	Office of Weather and Air Quality, OAR
Cosgrove, Brian	Office of Water Prediction, NWS
Farrar, Michael	Director, Environmental Modeling Center, NCEP, NWS
Gilbert, Kathryn	Deputy Director, OPC/WPC, NCEP, NWS
Gross, Brian	High Performance Computing and Communication Division, SO, CIO, HPCCD
Grumbine, Robert	Environmental Modeling Center, NCEP, NWS
Iredell, Mark	Environmental Modeling Center, NCEP, NWS
Lapenta, Bill	Director, National Centers for Environmental Prediction, NWS
Lin, S.J.	Geophysical Fluid Dynamics Laboratory, OAR
McQueen, Jeff	Environmental Modeling Center, NCEP, NWS
Mehra, Avichal	Environmental Modeling Center, NCEP, NWS
Michaud, David	Director, Office of Central Processing
Stajner, Ivanka	Office of Science and Technology Integration, NWS
Toepfer, Fred	Program Manager, Office of Science and Technology Integration, NWS
Tolman, Hendrik	Senior Advisor for Advanced Modeling Systems, Office of Science and Technology Integration, NWS
Zhu, Yuejian	Environmental Modeling Center, NCEP, NWS

Appendix F Glossary

3DVAR	3-D Variational data assimilation
4DVAR	4-D Variational data assimilation
AFSO	Analysis, Forecast and Support Office (NWS)
ARL	Air Resources Laboratory (OAR)
BUFR	Binary Universal Form for the Representation of meteorological data
CaRDS	Capabilities and Requirements Decision Support
CESM	Community Earth System Model (NCAR)
CICE	Los Alamos Sea Ice Model
CAM	Convection Allowing Model
CAPE	Column Available Potential Energy
CCPP	Community Common Physics Package (DTC)
CESM	Community Earth System Model (UCAR)
CFS	Climate Forecast System
CFSRR	Climate Forecast System Reforecast and Reanalysis
CGS	Climate Guidance System
CONUS	Continental United States (lower 48 states)
CO-OPS	Center for Operational Oceanographic Products and Services (NOS)
CPC	Climate Prediction Center
DA	Data Assimilation
DHS	Department of Homeland Security
DTC	Developmental Testbed Center (NCAR)
DoD	Department of Defense
DoE	Department of Energy
ECMWF	European Centre for Medium Range Weather Forecasting
ENSO	El Niño Southern Oscillation
ESMF	Earth System Modeling Framework
ESRL	Earth Systems Research Laboratory (OAR)
FNMOC	Fleet Numerical Meteorological and Oceanographic Center
GDAS	Global Data Assimilation System for the atmosphere
GEFS	Global Ensemble Forecast System
GFS	Global Forecast System
GFDL	Geophysical Fluid Dynamics Laboratory (OAR)
GOCART	Goddard Chemistry Aerosol Radiation and Transport air quality model
GRIB	GRIdded Binary (WMO data format)
GSI	Gridpoint Statistical Interpolation DA software
GWES	Global Wave Ensemble System
HDF	Hierarchical Data Format
HFIP	Hurricane Forecast Improvement Project
HNMMB	Hurricane NMMB model

HRRR	High Resolution Rapid Refresh deterministic mesoscale weather model
HWRF	Hurricane WRF model
HYCOM	Hybrid Coordinate Ocean Model
IDSS	Impact-based Decision Support Services
IOC	Initial Operational Capability
IPD	Interoperable Physics Driver
JCSDA	Joint Center of Satellite Data Assimilation
JEDI	Joint Effort for Data assimilation Integration (JCSDA)
KISS	Keep Ice'S Simplicity ice model
LANL	Los Alamos National Laboratory (DoE)
MAG	Models Analysis and Guidance website (NCO)
MDL	Meteorological Development Laboratory (NWS)
MET	Model Evaluation Tool (NCAR)
MODE	Method for Object-Based Diagnostics Evaluation
MODIS	XXXX
MJO	Madden-Julian Oscillation
MOM	Modular Ocean Model
NASA	National Aeronautics and Space Administration
NDFD	National Digital Forecast Database
NOAA	National Oceanic and Atmospheric Administration
NAM	North American Mesoscale regional model
NAEFS	North American Ensemble Forecast System
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NDFD	National Digital Forecast DAtabase
NEMS	NCEP Environmental Modeling System
NESPC	National Erath System Prediction Capability
NetCDF	Network Common Data Form
NFWES	NCEP FNMOC Wave Ensemble System
NGGPS	Next Generation Global Prediction System
NHC	National Hurricane Center
NOMADS	NOAA National Operational Model Archive & Distribution System
NOS	National Ocean Services (NOAA Line Office)
PSN	NCEP Production Suite
NUOPC	National Unified Operational Prediction Capability
NWM	National Water Model
NWPS	Nearshore Wave Prediction System
NWS	National Weather Service (NOAA Line Office)
NUMTF	NOAA Unified Modeling Task Force (NOAA RC)
NUOPC	National Unified Operational Prediction Capability
OAR	Oceanic an Atmospheric Research (NOAA line office)
OGS	Outlook Guidance System
OPC	Ocean Prediction Center

OPeNDAP	Open-source Project for a Network Data Access Protocol
OSTI	Office of Science and Technology Integration (NWS)
OSTP	Office of Science and Technology Policy (White House)
OWP	Office of Water Prediction (NWS)
R&D	Research and Development
RAP	Rapid updating low-resolution mesoscale model providing boundary data for the HRRR.
RC	NOAA's Research Council
RRGS	Rapid Refresh Guidance System
RRs	Reforecasts and Reanalyses
RTGSST	Real Time Global Sea Surface Temperature
RTMA	Real Time Mesoscale Analysis
RTOFS	Real-Time Ocean Forecast System
RUA	Rapidly Updated Analysis
SIP	Strategic Implementation Plan
SIS2	Sea ice Simulator 2 ice model
SOLAS	Safety of Life at Sea.
SP	Strategic Plan
SREF	Short Range Ensemble Forecast regional model system
SST	Sea Surface Temperature
SWAN	Simulating Waves Nearshore wind wave model
SWPC	Space Weather Prediction Center (NWS/NCEP)
T2O	Transition to Operations
THREDDS	Thematic Realtime Environmental Distributed Data Services
UCACN	UCAR Community Advisory Committee for NCEP
UCAR	University Corporation for Atmospheric Research
UDA	Unified Data Assimilation
UGCM	Unified Global Coupled Model
UMAC	UCACN Model Advisory Committee
UPP	Unified Post Processor
URMA	UnRestricted Mesoscale Analysis
VV	Validation and Verification
WCOSS	Weather and Climate Operational Supercomputing System
WGS	Weather Guidance System
WMO	World Meteorological Organization
WoFGS	Warn on Forecast Guidance System
WRF	Weather Research and Forecasting mesoscale atmospheric model
WW3	WAVEWATCH III wind wave model

Appendix G Revision History

Date	Ver.	Author/Editor	Comment
09/26/2016	0.1	Hendrik Tolman	Initial "brain dump"
10/13/2016	0.2	Mike Farrar	Initial comments on version 0,1
10/31/2016	0.3	Hendrik Tolman	Second draft
11/10/2016	0.4	Hendrik Tolman	Draft to share with SIP workshop
11/21/2016	0.5	Hendrik Tolman	Draft prepared to gather information from selected contributors (gap filling, references, etc.)
12/05/2016	0.6	Hendrik Tolman	Draft for broader distribution with partial input requested for version 0.5