April-June 2021

UFS QUARTERLY

Bulletin of the UFS Community

NOAA and the UN Decade of Ocean Sciences

Photo: Jeremy Potter/Hidden Ocean 2005

ALSO IN THIS ISSUE

doi.org/10.25923/mpsh-7y81

EPIC

By DaNa Carlis

The Time is Now for the Earth Prediction Innovation Center

DaNa Carlis *(Photo: Dr. Lydia Carlis/C-Suite Pics and Eymagination Imaging)*

Wow! The Earth Prediction Innovation Center (EPIC) is now a reality. I'm extremely excited and know that the weather community is feeling the same joy and optimism now that EPIC's two-year planning process is finally behind us. On April 26, NOAA announced that Raytheon Intelligence & Space (RI&S) would be the development partner that would unite the community in developing the most user-friendly and user-accessible Earth modeling system in the world. The next year is crucial. Academia, industry, and NOAA must come together to support EPIC's mission of being the catalyst for community research and modeling innovations that continually inform and accelerate advances in our nation's operational forecast modeling systems.

After having the honor of being the first program manager of EPIC, I've moved on to become the Deputy Director of NOAA's Global Systems Laboratory (GSL). I was recently asked back to support the program in an acting capacity. I firmly believe that EPIC will be one of the most impactful programs developed in partnership with the weather enterprise to enable the research and development community to work closely with NOAA's National Weather Service. The potential for EPIC through its support of the Unified Forecast System (UFS) and community engagement efforts will have a significant impact on forecast improvements that will aid in the delivery of services to the American people for many years to come.

I feel it's imperative to recognize the contributions from the community made up of NOAA and extramural members that spent intellectual capital and years of planning to get this program off the ground. There are too many people to name, but many of you know who you are, and I'm incredibly grateful for your guidance. I will always celebrate the visionary leadership of two individuals in particular: Dr. Bill Lapenta, former Director of the National Centers for Environmental Prediction (NCEP), and Dr. Neil Jacobs, former Acting NOAA Administrator, EPIC wouldn't be a reality without their determination in getting EPIC into legislation and the program established with a $13M budget in NOAA's Weather Program Office.

In closing, I'd like to share that the opportunities are infinite for the community through EPIC. Success starts with engaging the community in the model development process that was troublesome to non-NOAA researchers for so long. Through EPIC, we will facilitate open and transparent development processes and train the next generation of model developers that will have the opportunity to contribute their ideas for the protection of life and property while building their scientific R&D careers using the UFS. The time is now, and the weather community is ready to tackle some of our nation's most significant challenges to build the most accurate and reliable operational forecast model in the world.

Dr. DaNa Carlis is Acting Program Manager for the EPIC Program at the Weather Program Office (WPO) and Deputy Director of the Global Systems Laboratory (GSL), OAR/NOAA.

We are thankful for the support from the ***UFS Steering Committee*** *and the* ***UFS Communications & Outreach Team****.*

Thank ***you****, and forgive us if we forgot someone!*

THE UNITED NATIONS DECADE OF OCEAN SCIENCES

By Eric Bayler, Ann-Christine Zinkann and Theresa Keith

NOAA oceanographic vessel Fairweather in Glacier Bay, Alaska (Photo courtesy of Fairweather Crew and Officers)

An Opportunity for Expansion, Integration, and Co-design

The United Nations Decade of Ocean Sciences and Sustainable Development 2021-2030 or Ocean Decade, strives to expand scientific understanding and build partnerships to ensure "The science we need for the ocean we want". During the next ten years, a vital part of ensuring the success and ambition of the Ocean Decade will be collaborations across disciplines, stakeholder groups and countries around the globe. These ten years offer a tremendous opportunity to bring together the entire community, from scientists to end-users of the science and services that result, to co-design solutions for understanding ocean conditions, ensuring sustainable utilization of our ocean and coasts, and protecting communities from ocean-related hazards.

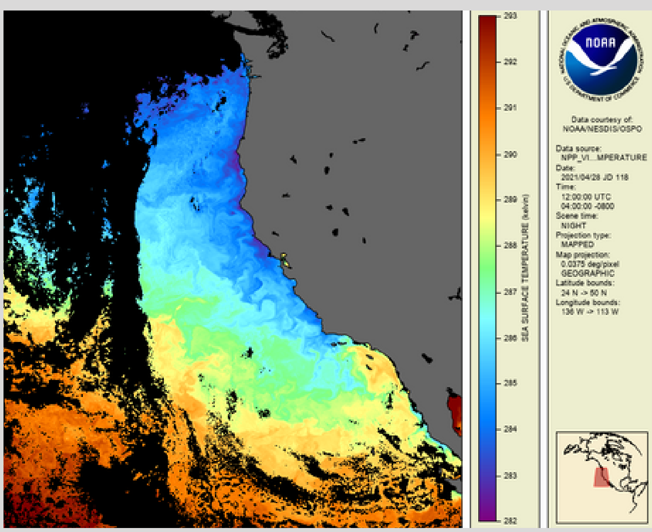
As one of the seven expected outcomes of the Ocean Decade, "A Predicted Ocean" captures the international consensus on our need to understand and explore a changing ocean, including physical, chemical and biological components and interactions. Ocean observations become more valuable to society when they are transformed through analyses into predictions and outputs that inform decision-making, and thereby provide societal benefits. For instance, NOAA's Unified Forecast System (UFS) adds value to the observation value chain through data-assimilation modeling to constrain and inform results for greater forecast skill to enhance informed decision-making. Large, cross-collaborative efforts like UFS serve to coalesce, enable, implement, and enhance the global operational oceanography enterprise and our global, regional and local predictive capacity.

WCOFS as a Model for the Ocean Decade

The Ocean Decade strongly emphasizes capacity-building and co-development to facilitate utility and sustainability of actions and their impact. The development of NOAA's newly implemented West Coast Operational Forecast System (WCOFS) reflects this approach, combining the U.S. Integrated Ocean Observing System (IOOS) West Coast

Regional Association's stakeholders in the development from the project's outset and transitioning the expertise and experience of external partners into NOAA's operational capacity. The range of stakeholders spanned the federal government as well as the state governments of Washington, Oregon, and California, Native American communities, private sector organizations and academia. The WCOFS embodies the attributes of Ocean Decade actions, while it serves as a pathfinder for NOAA's operational oceanography enterprise. It incorporates partner research and development; transitioning experience, expertise and capabilities to NOAA; and integrating stakeholder and user requirements, applications, and priorities.

The forecasting community has been actively responding to international and domestic calls for UN Decade Actions. In the realm of ocean physics and biogeochemical/ecosystem modeling, NOAA is a partner on two endorsed Ocean Decade Programmes regarding numerical modeling, data assimilation, and applications (ForeSea and CoastPredict), targeting sustained operational oceanography across time and space scales, applications and societal benefits. The National



The WCOFS, spanning the U.S. West Coast from Baja California to Canada and extending approximately 1,000 kilometers offshore, models the ocean's physics at four-kilometer resolution using the Regional Ocean Modeling System (ROMS) and 4D-variational (4D-Var) data assimilation. The WCOFS extends data assimilation into the National Ocean Service's (NOS) operational forecasting for the first time, thereby significantly advancing NOAA's UFS capabilities, increasing the value extracted from satellite (altimetry, sea-surface temperature) and coastal HF-radar ocean surface current observations, and expanding leverageable capacity, applications, and output. WCOFS embodies the Ocean Decade's capacity-building and co-development objectives by integrating regional stakeholder expertise and needs into NOAA's operational capabilities.

Marine Fisheries Service is leading an Ocean Decade pipeline Programme entitled SUPREME (SUstainability, Predictability and REsilience of Marine Ecosystems) that proposes to exploit the UFS Modular Ocean Model 6 at seasonal and longer time scales. The forecasting community has also responded to a call for large-scale, ambitious "Ocean Shots" from the U.S. National Committee for the Decade with two ideas: Integrated Coastal Ocean Forecasting Systems and OceanPredict.US. The Ocean Shots solicitation serves as America's incubator for transformational Decade actions.

UFS and Ocean Decade Opportunities

There are ample opportunities to participate in the Ocean Decade and embrace its convergence of ideas, resources, communities and stakeholders. The UFS community is encouraged to consider the endorsed Decade actions announced on World Oceans Day (June 8th), as well as the Ocean Shots directory for potential collaborators. Additional solicitations for Ocean Decade actions and Ocean Shots will occur throughout the Decade; the next official solicitation for actions is expected in fall 2021 and the deadline for the second round of Ocean Shots is July 1st. The UFS community is also encouraged to participate in a series of Ocean Decade "Laboratories" – 48 hour virtual events to mobilize diverse representation in ocean science, showcase undertaken efforts, strengthen dialog, and raise awareness for the Ocean Decade; the two most UFS-relevant laboratories are the Predicted Ocean Laboratory (September 15-16, 2021) and the Safe Ocean Laboratory (TBS April, 2022).
The Ocean Decade enables us to rethink our approach to ocean science. It is an invitation to scientists around the world to participate in a unique opportunity to expand scientific understanding, build partnerships across geographic and disciplinary boundaries, and operationalize science for the benefit of society. By the end of the Ocean Decade, not only will the ocean be better understood, the science community will have built strong collaborations that should last for years to come.

Eric Bayler is the Manager for Ocean Data Assimilation Programs at NOAA's Center for Satellite Applications and Research
Ann-Christine Zinkann is a UCAR International Ocean Program Specialist at NOAA
Theresa Keith is a Knauss Marine Policy Fellow at NOAA Research

THE UFS R2O PROJECT

By Jeff Whitaker, Jim Kinter and Vijay Tallapragada

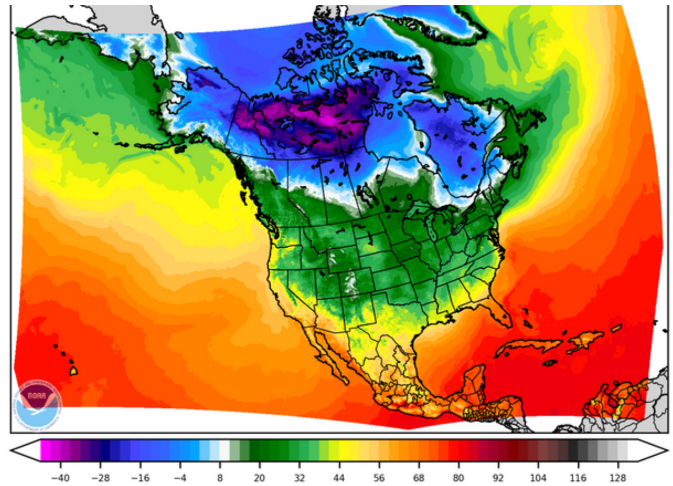
Celebrating the First Anniversary of the UFS R2O Project

Flash back to late 2019 — the Unified Forecast System (UFS) concept was finally coming to fruition. A new, open-source, community-based Earth-modeling system is being established that will form the basis for NOAA's operational prediction systems for decades to come. Sounds wonderful, right? But wait — how is this actually going to work? How will new innovations from the research community actually be integrated into NOAA's UFS-based prediction system, tested and implemented in operations?

That's the conversation we were having at the beginning of 2020. It was clear that the old way of doing things, with separate funding and management for projects in NOAA research labs, NOAA operations, universities and cooperative institutes was not up to the task. Thus, the concept for the UFS Research-to-Operations (UFS-R2O) project was born. A new way of doing business, with coordinated funding and project management across NOAA aimed at integrating new research into the operational UFS.

The UFS-R2O project was conceived with a focus on leveraging the nascent UFS community to build two new operational predictions systems from the ground up - a six-way global coupled (atmosphere/ocean/land/sea-ice/wave/aerosol) ensemble system for medium-range and seasonal to sub-seasonal (S2S) prediction, and a regional, high-resolution hourly-updating and convection-allowing ensemble system for prediction of severe weather. The project began in July 2020 as a collaboration between the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center, 8 NOAA research labs, The National Center for Atmospheric Research (NCAR), the Naval Research Lab and 6 universities and Cooperative Institutes.

Here we are almost a year later, and although we have a long way to go to achieve our goals, we have made some significant progress. Most importantly, we have built a collaborative framework and established cross-institutional teams that are working together to achieve the common goal of improving the nation's



The UFS R2O Project has advanced NOAA's Rapid Refresh Forecast System (RRFS) prediction of temperatures over the continental USA.

operational forecasts. The "U" in UFS means unified, not only because a single modeling framework is being used across the full range of forecast applications, but also because we have a unified approach and a unified development team, with NOAA and non-NOAA team members working together toward a common goal.

"Those of us inside NOAA have learned that the value of working with people outside the organization who bring a fresh perspective and new ideas far exceeds the cost, and those of us outside NOAA have gained new respect for the challenges inherent in an operational forecasting environment. Despite some growing pains and challenges posed by a global pandemic, we have some significant accomplishments under our belt after one year," says Dorothy Koch, Director of the Weather Program Office (WPO) at NOAA's Office of Oceanic and Atmospheric Research (OAR).

First off, the global coupled prediction system that will ultimately support both the operational NOAA Global Ensemble Forecast System (GEFS) version 13 and Global Forecast System (GFS) version 17 is beginning to come together. A series of retrospective 35-day coupled forecasts for the period 2011-2018 have been completed using prototype versions of the coupled system, each with incremental improvements to the component models and the coupling infrastructure. These improvements include upgrades to the atmospheric physics suite to address known model systematic biases.

A prototype coupled data assimilation system has been developed that can update the ocean, sea-ice and atmospheric states, and will soon be extended to include land state updates. This coupled data assimilation system will be used to generate a 30-year reanalysis of the coupled system. Stochastic parameterizations of model uncertainty, currently operational in the atmospheric component, are being extended to the ocean and land components so that ensemble predictions will more accurately represent forecast uncertainty in the coupled system. An in-line atmospheric aerosol prediction capability is being tested, which allows aerosol feedbacks through the atmospheric physics.

"All of these activities are supported by the development of robust and extensible software infrastructures for model component coupling, data assimilation and forecast verification/validation. Crucially, this is all happening in an open, collaborative environment using github code repositories that are accessible to the entire UFS community," adds Jamese Sims, Acting Director of the Office of Science and Technology Integration (OSTI) Modeling Division with NOAA's National Weather Service (NWS).

Secondly, the development of a limited-area convective-scale short-range ensemble prediction system that will form the basis for the Rapid Refresh Forecast System (RRFS) and the Hurricane Analysis and Forecast System (HAFS) is moving forward toward operational implementation. The UFS convective-scale limited area configuration utilizes the same software infrastructure as the global coupled system, with the same atmospheric dynamical core. This will allow for considerable simplification of the NOAA production suite, which now consists of several separate modelling systems running for hurricane and severe weather prediction applications.

Baseline configurations for the UFS hurricane application (HAFS) and the high-resolution hourly updating continental-scale system (RRFS) have been established, and will form the basis for testing new developments culminating in operational implementations in the 2023 timeframe. A public release of the regional high-resolution limited-area UFS application (the short-range weather or 'SRW' application) that underpins both the HAFS and the RRFS is now available (see article in the Winter edition of this Bulletin).

Since even an hourly updating system is not sufficient in rapidly evolving severe weather situations, a Three-Dimensional Real Time Mesoscale Analysis System (3D-RTMA) is being developed that will update hourly RRFS forecasts with newly arriving observations. The 3D-RTMA system, also scheduled for operational implementation in 2023, will replace the current surface-based 2D-RTMA system, enabling improved situational awareness for aviation and severe-weather applications by providing a depiction of the full 3D atmospheric state at 15 minute resolution.

"These are all major steps toward the ultimate goal of an operational, community-based unified forecast system that produces the best forecast guidance possible from convective to seasonal time scales. We hope that the collaborative environment that we are building will form the basis for ever more rapid improvements by making the process of transitioning new developments contributed by the UFS community into operational prediction systems faster and more efficient," says Brian Gross, Director of NWS's Environmental Modeling Center (EMC) at NCEP.

We want to take this opportunity to thank our collaborators for their dedication and hard work over the past year. It's truly inspiring to see what can be accomplished when artificial organizational boundaries are relaxed and people with a shared passion and vision are brought together to build something new. We look forward to refining the process to make the collaboration even more productive, and bringing in new team members from the UFS community to contribute to the improvement of the nation's operational prediction systems for the benefit of all of us.

***Jeff Whitaker** (NOAA ESRL PSL), **Vijay Tallapragada** (NOAA NCEP EMC) and **Jim Kinter** (George Mason University) are co-equal principal investigators coordinating the work of over 200 participants in the UFS-R2O Project*

A Tale To Wag The Dog

By Susan Jasko

If I ask you to picture the National Oceanic and Atmospheric Administration (NOAA), what comes to mind? The entrance to the National Weather Service (NWS) Headquarters in Silver Spring, MD? Or perhaps NOAA's Center for Weather and Climate Prediction (NCWCP) in College Park, MD?

Do you picture the computer stations? The satellites? The guidance products?

Maybe you picture the people.

Front view of the NOAA Center for Weather and Climate Prediction (NCWCP) building in College Park, Maryland.

The women and men who comprise the NOAA workforce, and who, through their labors and intentions, actually are NOAA.

In that same way, the Unified Forecast System (UFS) is both a set of code AND the people who develop and make the code work. Then there are the others whose intellectual work needs the code to deepen our collective understanding of the inner-workings of Earth's environment. Perhaps most visible are those who work to put that knowledge to use in the service of protecting life and property, in the service of the greater good.

Richard (Ricky) Rood is a co-chair of the UFS Steering Committee. He and I met to talk about the history and future of the UFS.

About 6 years ago, the late Bill Lapenta approached me. My expertise is in communications. The study of human communication has a rich and complex history, and my background and training include the social and behavioral sciences and the humanities. In pursuit of my doctorate I learned about quantitative and qualitative methods, philosophy of science, linguistics and language, rhetoric, and to respect a range of ways of knowing. I learned how to apply those ways of thinking and knowing the world to a range of settings and contexts, including organizations. I have a long history with the meteorological communities.

Ricky Rood had signed on to working with Bill. They were part of a group working on a broad goal of initiating and nurturing organizational change, specifically in the way NOAA thinks about and carries out numerical modeling. What was clear to this group was that changing NOAA's approach to numerical modeling would require making organizational changes that that would bring thinking and process in alignment with the desired outcome of full community engagement in the effort. In other words, they realized that organizational change that reached down into the metaphorical weeds would be required if community modeling were to be achieved. A true community-based modeling effort would mean resetting people's understanding of NOAA's roles in getting to the next generation of numerical models – at the foundation was NOAA would be working as part of the community, as opposed to, for example, making models available to the community.

The time was right, according to Ricky, for numerical modeling to play the starring role in fostering deep organizational change. There was much public attention to and debate about the American ability to forecast large and significant storms accurately in the wake of Superstorm Sandy. That public discussion included some who inhabited the halls of congress, and such discussion often included a comparison with the "European" model. The European model consistently outperformed the American model. Seeing that as an opportunity for growth and change, Bill decided that a fresh approach to modeling was needed. He chartered an external advisory committee, the UMAC, with Rood as co-Chair. Bill committed to improve research community involvement in key decision-making in NOAA regarding the future of numerical modeling.

NOAA committed to major changes, including modernization of the model's fluid dynamics. There was a commitment to coupled modeling and simplification of the production suite using community infrastructure. Ricky and several others became instrumental in framing and designing what became the Unified Forecast System. And while it is tempting to understand that phrase as referring primarily to a set of code, in fact, the weather forecast system in the US is quite complex. It is essential to think of the code how it is developed, tested, and used, the governance, if there is to be transformational change to NOAA working in partnership with academic, private-sector, and federal communities. The UFS is a symbolic social system, and its true essence are people working together on shared goals.

One of the critical characteristics of the late 19th and much of the 20th century is called specialization. Specialization led to “silos” of knowledge and expertise. Crossing those boundaries has proven challenging. In the case of numerical modeling, it meant that although much innovation was happening in the research community, very little of that innovation was making its way in operations. Ricky added that research-based innovation often times DID make it into the European model and operations. A UFS goal was to lower the silo walls between NOAA and federal, academic, and private sector researchers. Indeed, there was a goal to challenge organizational barriers within NOAA. Although differentiated responsibilities require separation of institutional roles, this new shared, more open space, with easy access for qualified individuals, would enable a spirit of collaboration, foster mutual respect based on increased understanding of the perspective of others, increase the level and extent of investment by a wider range of the forecast and modeling community, and create a clearer and less obstacle strewn pathway between research and operations.

Richard (Ricky) Rood is a co-chair of the UFS Steering Committee and a professor of climate and space sciences and engineering at the University of Michigan in Ann Arbor.

Organizational changes of this magnitude require a clear vision and strong focus, and according to Ricky, the UFS leadership holds three goals to establish a decision-making context in which all interested parties may participate. Those goals are to 1) seek scientific excellence of numerical products; 2) simplify the model suite balanced against cost; and 3) sharpen and amplify the applications of the model in both the research and forecasting communities.

In thinking about how the numerical modeling fits into the forecast process, Ricky said that the forecasting needs put some boundaries on the UFS but that trying to balance that against the kind of research freedom academic researchers sometimes prefer is an ongoing organizational challenge. He told me that in order to determine what goes forward into operations the community would need to be sure that any development rested on sufficient robust scientific merit and that the change would be easy enough to use. There is a requirement for known transparent goals, systematic testing throughout the inclusion of innovations, and the UFS acting as a organization anchored in collective evidence-based decision making.

And, of course, the changes also need to help create improved forecast guidance in the eyes of end users, which includes the public.

There has been substantial progress in improving the scientific foundation of NOAA's operational weather models. These improvements have led to better numerical guidance, and more importantly, there are productive paths to accelerated improvements. The applications and codes are being considered holistically and simplification of the legacy systems is evolving. Access to code and engagement of the community is improved.

Still, much work lies ahead to ensure that the UFS succeeds at both creating numerical model improvements and serving as a lever of change in how NOAA understands its own position as a member of this community model and a steward of a new community designed to overcome the silos separating research from operations.

Fortunately, as Ricky pointed out, the UFS leadership has taken great pains to keep records and create and secure documentation. The tremendous volume of work done by so many people since the first UFS gathering was held exits in the form of key documents that have been archived for easy reference. The web portal was stood up and continues to evolve, this newsletter is distributed widely, and a Twitter account touts code releases and updates. But more importantly, the archived documents and the ongoing work of members of the various working groups represents a form of continuity Ricky notes as essential to present and future success.

Building and nurturing community also requires persistent, intentional, thoughtful, and well-designed communication efforts. Ricky emphasized the need to continue to hold meetings with forecasters to gain their insights and better understanding their needs; the focus on verification and validation to anchor the organization on scientific principles; gathering metrics for all of the various existing applications; using surveys; and participating in professional association meetings through presentations, Town Halls, and workshops.

And when Ricky eventually exits the UFS stage, he said such transitions make continuity all the more crucial. The products and the behavior of the community are the focus; the UFS must build on shared understanding and goals. It needs to persist, rather than be reinvented with each new leader and each new program. Underlying that capacity is the development of a culture based on scheduled application releases, which integrate, together, all aspects of a system to improve usability and community engagement. This underscores a need to re-activate an integrated planning process in much the same way that the forecast offices use Integrated Warning Teams to plan for upcoming seasons in a way responsive to the needs of all of the partners involved.

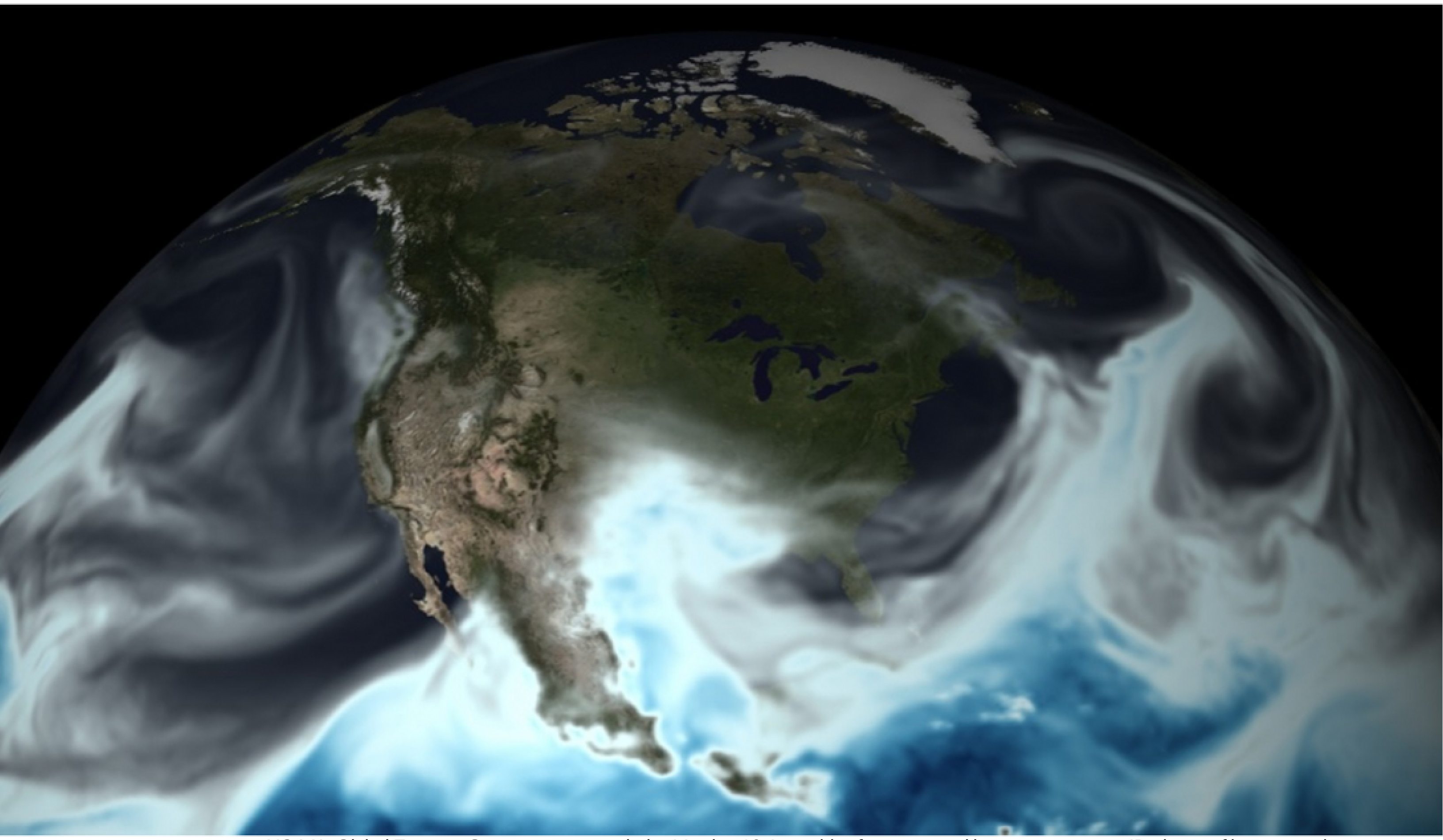
For any community to not just survive but to thrive, the people who make up that community must exercise good stewardship – such as the kind Bill Lapenta demonstrated and Ricky still embodies.

Susan Jasko *is the UFS Community Communications and Outreach Co-Chair and Senior Research Scientist at the Center for Advanced Public Safety, University of Alabama*

UFS
UNIFIED FORECAST SYSTEM

THE COUPLED ATMOSPHERE-WAVES GFS VERSION 16

By Fanglin Yang, Russ Treadon, Geoff Manikin, Vijay Tallapragada and Daryl Kleist



NOAA's Global Forecast System was upgraded to Version 16. It provides forecasters with a more accurate 4D picture of how a weather system will evolve. Gray, blue and white colors depict moisture in the atmosphere on May 11, 2016, over North America. (NOAA)

NOAA'S Global Forecast System and Data Assimilation Upgrade

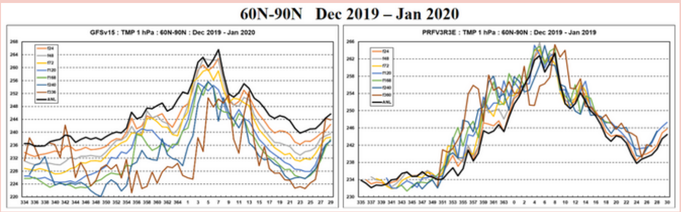
On March 21, 2021, the National Centers for Environmental Prediction (NCEP) upgraded the Global Forecast System (GFS) and Global Data Assimilation System (GDAS) from version 15.3 to 16.0. A highlight of this upgrade was the introduction of a coupled global-scale wave component using the community model WAVEWATCH III. A number of other changes made to the GFS and GDAS systems have resulted in major improvements to the forecast system.

GFSv16 saw significant improvement in physics and data assimilation. Model vertical configuration was increased from 64 to 127 vertical levels. Physics upgrades featured new sub-grid scale parameterizations, a scale-aware total kinetic energy based eddy diffusivity mass flux scheme, microphysics scheme for computing ice cloud effective radius, and a revised ground heat flux calculation for snow-covered surfaces.

Data assimilation (DA) changes included high-density flight-level observations in tropical storm environments for the first time in operations for the GFS, a Local Ensemble Kalman Filter (LETKF), a new 4-Dimensional Incremental Analysis Update (4D-IAU) technique, updated variational quality control, updated aircraft bias correction with safeguards, assimilation of additional observation platforms, and an upgraded Community Radiative Transfer Model (CRTM). Other important features of physics and DA upgrades are detailed in the next page.

Doubling the forecast model vertical resolution inevitably increases file sizes for both the forecast and data assimilation systems. To alleviate the added burden, the data format of model forecast output was changed from the binary NEMSIO format to compressed netCDF. A new parallel I/O was developed with updated netCDF and HDF libraries. As a result, the size of atmospheric forecast history files was reduced from 33.6 GB to 6.7 GB with lossy compression, and surface history file sizes were reduced from 2.8 GB to 1.1 GB with lossless compression. Further reducing I/O and speeding up the entire forecast system, the post-processing system was included in the model as a library to run with the model forecast using forecast data saved in memory for post processing.

GFS.v16 was evaluated before its implementation for operation by running retrospective experiments with fully cycled data assimilation for the period from May 2019 to March 2021 before the implementation date. An extra experiment was also carried out for the summer of 2018 to add more samples for hurricane forecast evaluation.



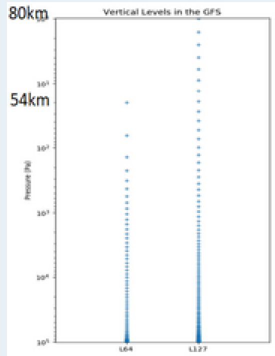
Improved 1-hPa Temperatures

GFS.v16 showed many improvements compared to GFS.v15, including improved 500-hPa height anomaly correlation scores and synoptic patterns in the medium range. Other highlights were better position of relevant frontal boundaries, mitigation of the low-level cold bias seen in GFS.v15 during the cool season, and increased identification of tropical cyclone threats with higher success ratio and longer lead times. Precipitation scores revealed improved QPF Equitable Threat Scores (ETS) and bias in the medium range and improved snowfall location and amounts with longer lead times. The new GFS also showed improved ability to capture the temperature profile in shallow, cold air masses and improved forecasts of stratospheric temperature, circulation, ozone and water vapor.

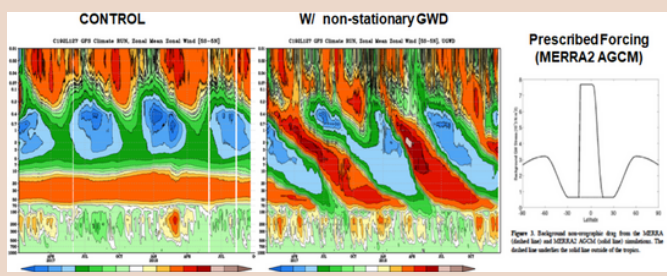
Data Assimilation Changes

- Observational precipitation to drive and spin up the uncoupled Global Land Data Assimilation System in the GDAS cycle, providing more realistic land initial conditions,
- Local Ensemble Kalman Filter (LETKF) with model space localization and linearized observation operator to replace the Ensemble Square Root Filter ,
- New 4-Dimensional Incremental Analysis Update (4D-IAU) technique (Figure 3),
- Activation of the Stochastic Kinetic Energy Backscatter (SKEB) scheme in GDAS ensemble forecasts,
- Updated variational Quality Control,
- Hilbert curve application to aircraft data,
- Updated aircraft bias correction with safeguards,
- Application of correlated observation error for CrIS over sea surfaces and IASI over sea and land,
- Assimilation of additional COSMIC-2 GNSS-RO data, AMSU-A channel 14 and ATMS channel 15 without bias correction,
- Assimilation of CSR data from ABI_G16, AHI_Himawari8, and SEVIRI_M08,
- Assimilation of AVHRR from NOAA-19 and Metop-B for near sea-surface temperature (NSST),
- Assimilation of high-density flight-level wind, temperature, and moisture observations in tropical storm environment,
- Assimilation of high-density flight-level wind, temperature, and moisture observations (HDOBS) in tropical storm environment for the first time in operations for the GFS,
- Upgraded Community Radiative Transfer Model (CRTM) v2.3.0.

Model Vertical Configuration



GFS v16.0 was the first major upgrade to the Finite Volume Cubed Sphere (FV3) dynamical core-based GFS, which replaced the spectral dynamical core in June 2019.
In this upgrade, the number of model vertical layers was increased from 64 to 127 and the model top was extended from the upper stratosphere (~55 km height) to the mesopause (~80 km height). The last time GFS vertical configuration was changed was in 2002.



Model Physics Changes

- New scheme to parameterize sub-grid scale stationary and non-stationary gravity waves,
- Scale-aware total kinetic energy based eddy diffusivity mass flux scheme for planetary boundary layer processes, advection of turbulence by grid-mean flows (moist processes, mass-flux representation for the nonlocal momentum mixing, EDMF parameterization for the stratocumulus-top-driven turbulence mixing, and interaction of TKE with cumulus convection),
- Updated calculation of solar radiation absorption by water clouds and cloud overlap assumptions,
- Updated GFDL microphysics scheme for ice cloud radius,
- Revised ground heat flux over snow covered surface in NOAH LSM, introducing vegetation impact on surface energy budget.

This project was carried out by NCEP's Environmental Modeling Center (EMC) with support of other NOAA centers and labs and the research community. EMC's Fanglin Yang and Russ Treadon served as GFS.v16 project co-leads and Vijay Tallapragada as the project manager. Geoff Manikin led the evaluation. Jun Wang, Catherine Thomas, Jose-Henrique Alves and Jessica Meixner played significant roles in the development of model infrastructure, data assimilation and wave coupling. Arun Chawla, Daryl Kleist and Avichal Mehra provided additional management support and scientific guidance.

A JEDI-BASED OCEAN DATA ASSIMILATION SYSTEM

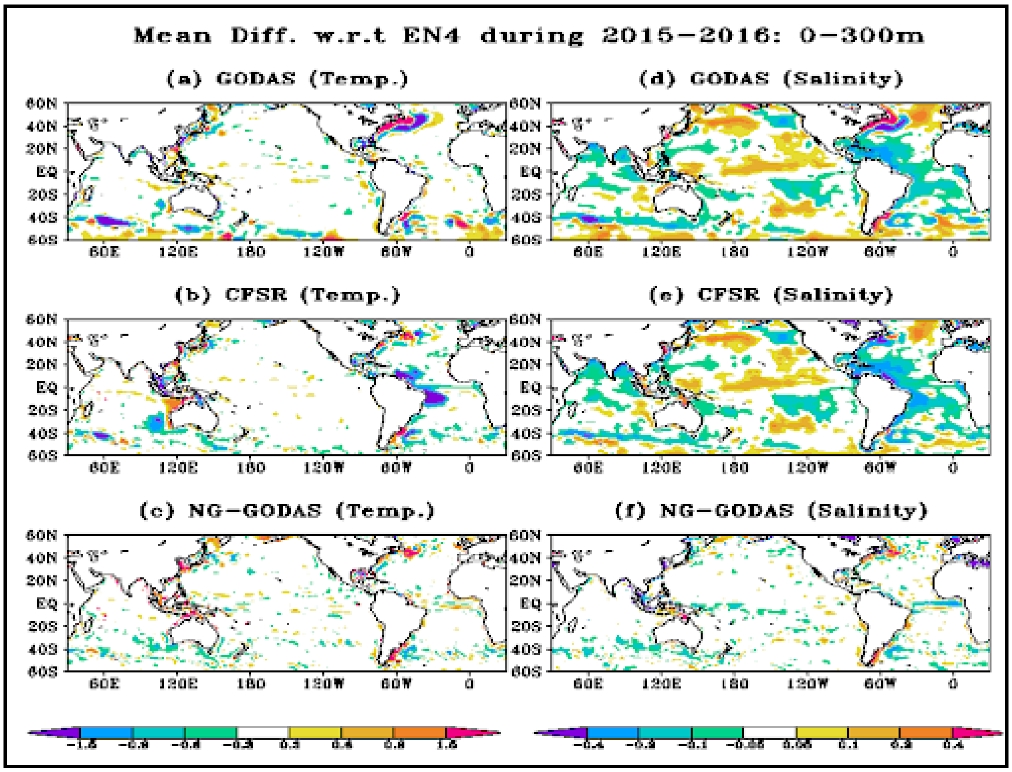
By Guillaume Vernieres, Travis Sluka, and Kat Shanahan

First Application of JEDI-based Ocean Sea Ice Reanalysis System for NOAA and UFS

On March 26, 2021, the Joint Center for Satellite Data Assimilation (JCSDA) announced a dedicated internal release of the soca-science repository for the National Ocean and Atmospheric Administration (NOAA) Global Ocean Data Assimilation System (GODAS). This internal release is important for NOAA's data assimilation efforts as a whole, but is particularly salient for the Unified Forecast System (UFS), which plans to utilize several applications of the JEDI-based data assimilation system.

This effort is the first application of a realistic, end to end JEDI-based data assimilation (DA) system for one of our partner agencies, and a demonstration of the flexibility of the JEDI.

Dr. Daryl Kleist, JCSDA Executive Team member and Chief of the Data Assimilation and Quality Control Group at EMC, indicates how important this accomplishment is for NOAA: "The collaboration and internal release that came from this coordinated effort is an incredible achievement and allows us to meet an agency milestone. This is the first operationally relevant application of a JEDI-based system for our agency, setting the stage for NCEP to phase out the current legacy GODAS system and begin working toward future JEDI-based applications and implementations."



Upper 300m heat (left column) and salt (right column) content for GODAS (top), CFSR (middle) and NG-GODAS (bottom). Analysis and figure provided by JieShun Zhu (NOAA-CPC). The NG-GODAS output was provided by Jong Kim (NOAA-EMC) and the EMC marine DA team.

The internal release was the culmination of three years of collaborative work between multiple groups including the Joint Effort for Data assimilation Integration (JEDI) and Sea-ice Ocean Coupled Assimilation (SOCA) teams at the JCSDA, as well as teams from NOAA's Environmental Modeling Center (EMC) and Climate Prediction Center (CPC).

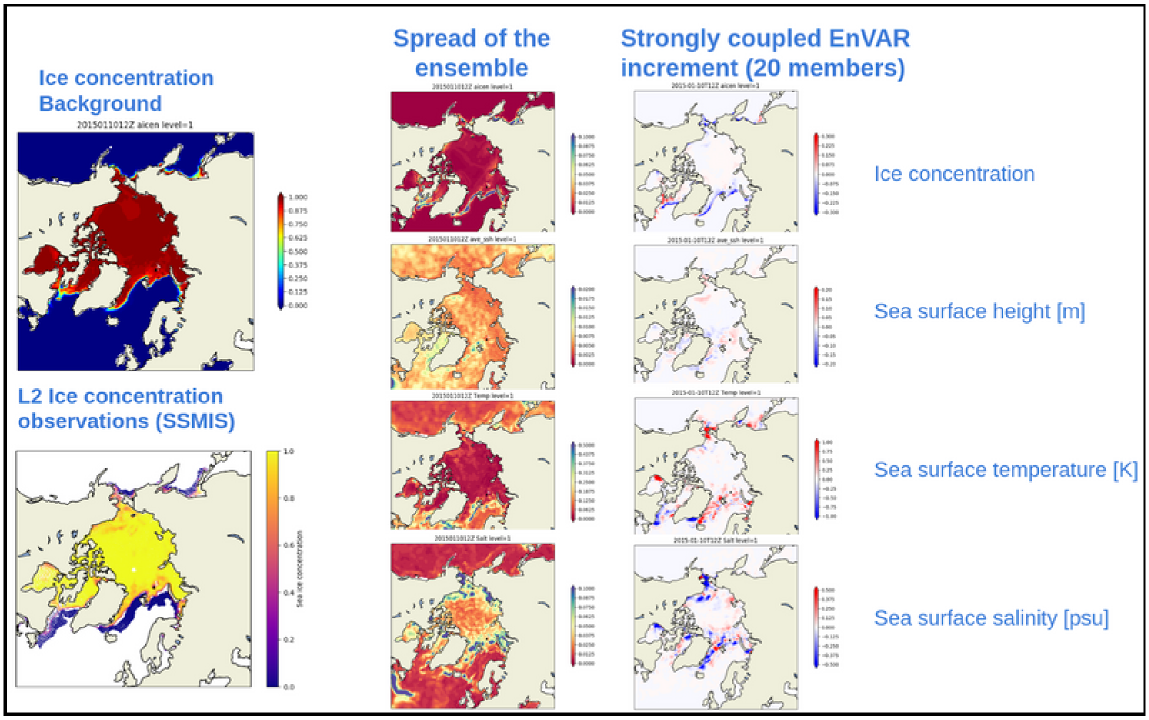


Illustration of a strongly coupled ocean and sea ice increment (write column) resulting from the assimilation of level 2 ice concentration from SSMIS (bottom left). The UFS ice concentration background is shown in the top left corner and the spread of the couple ocean ice UFS is shown in the middle column.

An eventual goal of the UFS is to initialize each of its components with JEDI-based data assimilation systems. The UFS is looking at three main applications of marine JEDI: ocean monitoring, initialization of the marine component of UFS for sub-seasonal forecasts and the use of the JEDI-based ocean sea ice data assimilation system for the initializations of the marine component of the coupled UFS within the weakly coupled DA effort lead by ESRL. Improved ocean monitoring capability was a large component of SOCA's latest internal release.

The target reanalysis system needed to use the Unified Forecast System (coupled MOM6-CICE6, UFS forecast model provided by EMC) and outperform the current NOAA marine climate reanalysis and monitoring system, as well as include the marine cryosphere as part of the data assimilation. Both of these goals were achieved, the first one at the second release while the cryosphere DA system was added in the dedicated GODAS release (NG-GODAS). An illustration of the improvement of upper ocean temperature and salt content is provided on the previous page, showing a clear improvement of the salt content over GODAS and CFSR against the EN4 objective analysis.

While EMC and CPC are using a resource conscious 3D variational analysis, the capability provided includes workflows for various ensemble DA algorithms and allows for strongly coupled DA between the sea ice and ocean. The figure above illustrates an application of the Ensemble Variation algorithm for strongly coupled DA and shows an example of a coupled ocean sea ice increment.

The system is continuously improved technically and scientifically on a daily basis, not only from scientists and engineers at the JCSDA, but also from collaborators at NASA-GMAO, NOAA-EMC and NOAA-CPC. The next challenging applications will tackle high resolution ocean data assimilation for the purpose of the initialization of the ocean component of NOAA's hurricane forecast system, the direct assimilation of radiances sensitive to ocean parameters and coupled data assimilation (ocean, sea ice and atmosphere) for the UFS and the NASA Goddard Earth Observing System (GEOS).

Guillaume Vernieres and Travis Sluka are Core Team Members of SOCA at the JCSDA, and Kat Shanahan is Program Coordinator for UCAR at the JCSDA

UFS FORECASTERS WORKSHOPS 2020 & 2021

By Jamese Sims, Dorothy Koch, Hendrik Tolman, and Deepthi Achuthavarier

Engaging the Forecast Community in UFS Model Development

With the advent of the Unified Forecast System (UFS), the operational model development at the National Weather Service (NWS) is becoming increasingly a collective effort that includes contributions from multiple NOAA labs, national agencies and university research groups. In this context, the UFS community as a whole seeks to better understand operational forecast challenges and requirements within the NWS. The NWS forecasters are the primary stakeholders of the UFS' operational products, and therefore, continued engagement with them is important to stay abreast of the real-world performance of the model and its general utility in society.

Feedback from stakeholders

The NWS forecast community includes 8 forecast centers within the National Centers for Environmental Prediction (NCEP), and local Weather Forecast Offices that come under 6 NWS regional headquarters including Alaska, Central, Eastern, Pacific, Southern and Western regions. Additionally, the NWS Office of Water Prediction (OWP), NWS Meteorological Development Laboratory (MDL) and the Federal Aviation Administration (FAA) are other stakeholders of the UFS and its operational products. Feedback from forecasters and stakeholders is one of the key drivers that informs the funding offices on research and development priorities. For the purposes of these modeling-oriented workshops, the NWS Center and Regional Offices served to represent the broader state, local and private forecast community.

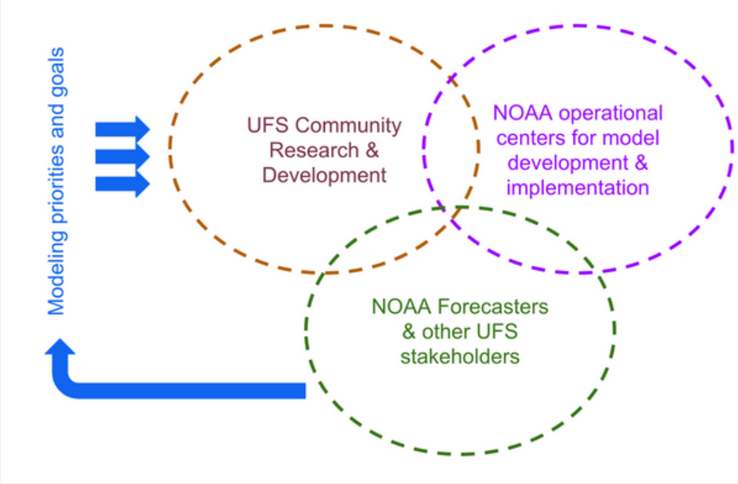
Forecasters workshops

In order to foster communication with the forecasting community, the NWS Office of Science and Technology Integration (OSTI) Modeling Program Division in coordination with the OSTI Research to Operations (R2O) Program conducted three workshops during November to February 2020-21. The key objective of these workshops was to identify top forecast priorities and modeling gaps within the operational weather prediction systems at the NWS, particularly focusing on the UFS Medium Range Weather/Subseasonal to Seasonal (MRW/S2S) and Short Range Weather (SRW) Applications (See more on UFS Applications here). Other goals of the workshop included articulating forecast system improvement goals to the NWS leadership and using workshop results as a starting point to streamline modeling requirement assessments with OSTI Analyze, Forecast and Support (AFS) Office.

Engaging stakeholders in the UFS

Feedback from forecasters and other stakeholders help to better understand model errors and thereby define development priorities.

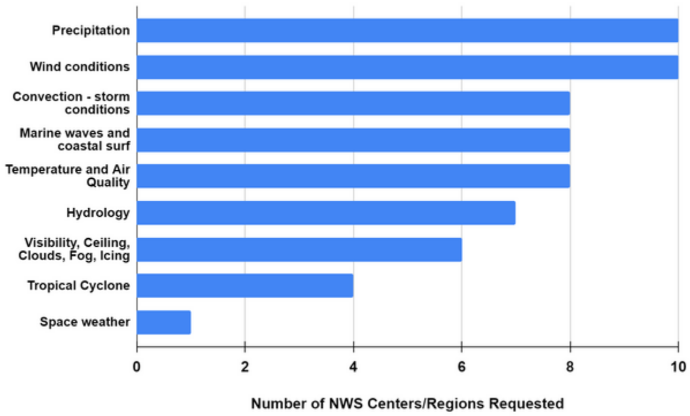
For a successful community model development and transition to operations, close coordination between the UFS research and development efforts, operational model development and implementation organizations - NCEP's Environmental Modeling Center (EMC) and Central Operations (NCO) - and the forecasting community is essential.



Prior to the first workshop, organizers launched a datacall, where each interested organization was requested to provide details on the UFS models and products relevant for their forecast mission, and outstanding issues and concerns in regard to forecast accuracy and model performance. The issues and requests collected from the datacall were organized into two broad categories: 1) those related to research and model development and 2) concerns related to computing, ensembles, data access and visualization. In the workshops conducted thus far, the focus has been on the first set of requests, considering their immediate impact on the model development goals. The second set is saved for consideration and discussion at a later time. A summary of the first set of concerns showed that precipitation and wind related issues topped the list and were closely followed by convection, marine issues and winds and air quality.

The workshops were of 3 hours duration each and included short presentations, interactive sessions, panel discussions and an open floor for question and answers. In addition to the forecasters and the modelers, representatives from the UFS community, NOAA's NWS and OAR Program Offices, OSTI AFS and a few UFS stakeholders outside of the NWS attended these workshops.

The first workshop (held on November 16, 2020) focused on discussing forecasters' concerns under a broad array of topics including convection, winds and terrain issues, precipitation, floods and Hydrology, tropical cyclones, visibility, marine/coastal issues, temperature and air quality, and space weather. These concerns were later synthesized and shared with the UFS model



Forecasters concerns by numbers: Summary of key Research and Development (R&D) concerns from forecasters. Precipitation and wind related issues topped the list.

developers and evaluators. The follow-up workshops held on January 29, 2021 and February 11, 2021 focused on key concerns of the UFS Medium Range Weather (MRW) and Short Range Weather (SRW) Applications, respectively. These workshops, led by the UFS Application leads, along with operational model developers and evaluators at the NCEP EMC, focused on connecting the forecast concerns with model specific issues and known biases.

Consolidated list of forecasters' concerns

The key outcome of the workshop is a finalized list of forecasters' requests for the UFS MRW and SRW Applications that consists of a total of 23 issues classified under 7 major topics, which are 1) Surface temperature and moisture, 2) Precipitation, 3) Convection, 4) Winds, 5) Tropical cyclones, 6) Marine waves, winds and sea ice and 7) Space weather.

Overall, the workshops brought the UFS community to a new level of synergetic coordination that strengthened the link between model development and forecasting challenges. Discussions between the forecasters and the modelers proved fruitful in that many forecast issues that appeared as independent disconnected items in the beginning of the meeting could later be tied to a few underlying model issues or development priorities. Some of the development priorities thus emerged are Boundary Layer (BL) over the land and ocean, air-sea coupling, land surface processes, land initialization, microphysics and sea ice, and marine winds and waves. The Model Evaluation Group (MEG) at the NCEP EMC, played a pivotal role in connecting the dots and bringing some of the key underlying issues to the forefront.

While the above list is a starting point that helps to shape the UFS development goals for the MRW/S2S and SRW Applications for the near-term, the UFS community is committed to continue the conversation and facilitate opportunities for ongoing engagement with the forecasters.

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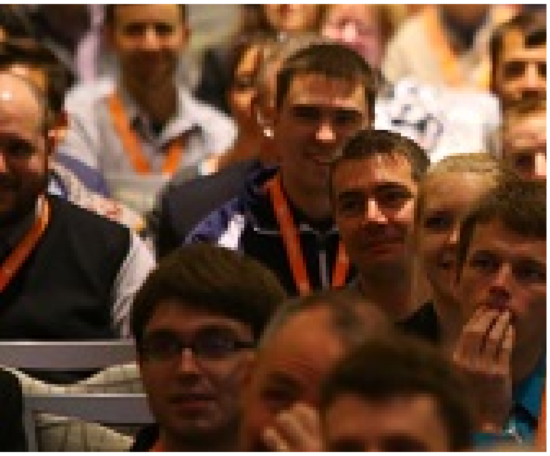
ANNUAL AMS MEETING 2022

By Neil Jacobs, Louisa Nance, Hendrik Tolman and Jose-Henrique Alves



AMERICAN METEOROLOGICAL SOCIETY
AMS 2022
102nd ANNUAL MEETING
HOUSTON | 23-27 JANUARY

The First Symposium on Earth Prediction Innovation and Community Modeling

The Opportunity

The Annual AMS meeting next year will host for the first time the Symposium on Earth Prediction Innovation and Community Modeling. The event provides an opportunity for the broad research community to share information about their latest developments and how these innovations are advancing the capabilities of community modeling systems. Topics in this symposium will include discussion on the motivation and process by which the community can work together to explore, validate, and integrate all aspects important to advancing weather and climate prediction. This open innovation approach spans everything from observation impact, model code, and software engineering to experimental design and computing architectures.

Stakeholders in public, private and academic sectors are encouraged to discuss how contributions to advance community modeling systems, such as the Unified Forecast System (UFS), should be evaluated using the Earth Prediction Innovation Center (EPIC) and the range of criteria that should be met as innovations advance though subsequent readiness levels. The community is invited to share ideas and experiences on both the development and operational forecasting side, as well as how the UFS and suite of National Center for Atmospheric Research (NCAR) modeling systems can serve as educational resources in the classroom.

Historical Perspective

In January 2019, NCAR and the National Oceanic and Atmospheric Administration (NOAA) established a Memorandum of Agreement to co-develop a common modeling infrastructure that would enable broader community engagement in advancing the Nation's weather and climate modeling capabilities for operational and research applications. Sharing infrastructure opens the door to researchers from academia, as well as research laboratories and national centers to collaborate on developing a community modeling resource. By sharing infrastructure, research innovations are more readily available across these modeling systems, enabling access and the ability to apply these innovations in a variety of contexts and conduct extensive testing.

The overall collaborative process benefits the entire research-to-operations value chain by tapping into a broader wealth of expertise to advance numerical guidance skill, thereby enabling stakeholders to meet their respective mission requirements.

Submit your abstract now!

__Neil Jacobs, Louisa Nance__ (DTC), __Hendrik Tolman__ (NOAA/NWS) and __Jose-Henrique Alves__ (NOAA Research) are Co-Chairs of the First Symposium on Earth Prediction Innovation and Community Modeling, AMS 2022