GSL Research to Operations/Applications/Community Use

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Tech Transfer Project Name	Transition Start Date	Deployment Date	Deployment By	Deployment Beneficiaries	Description of What was Deployed	Impact/Feedback
EARTH SYSTEM PREDICTION						
1. Rapid Refresh (RAP) v3 and High Resolution Rapid Refresh (HRRR) v2 models 2. Rapid Refresh (RAP) v4 and High Resolution Rapid Refresh (HRRR) v3 models 3.RAPv5 and HRRRv4 models (FINAL)	5/2015 6/10/2017 6/4/2019	8/23/2016 7/12/2018 12/2/2020	NWS/NCEP	NWS/NCEP, NWS/WFOs, FAA, NSSL, ARL, NCAR, Lincoln Labs	**RAPv3** - The 13k, hourly-updating regional RAP model was first deployed in NWS/NCEP's suite of operational models in May 2012 with RAPv2 improvements deployed in February 2014. The RAP is the parent model for the 3-km High-Resolution Rapid Refresh (HRRR) model providing boundary layer conditions for HRRR initialization. RAPv3 provides further improvements to storm environment, cloud, and winter-storm fields. **HRRRv2** - The 3km, CONUS, hourly-updating HRRR model was first deployed in NWS/NCEP's suite of operational models in September 2014. HRRRv2 provides forecasts in high detail, of critical weather events such as severe thunderstorms, flash flooding, and localized bands of heavy winter precipitation with significant reductions in model biases including a reduced warm/dry bias during the daytime in the warm season that improved convective forecasts. **RAPv4 and HRRRv3**- Improvements include forecast length extensions to help with day 2 forecasting efforts and with cloud and visibility forecasts. Significant improvement was made to high reflectivity/precipitation bias in first few hours of the forecast; to wind/turbulence guidance over terrain and more accurate thunderstorm forecasts with less high bias. New HRRR guidance is now available for Alaska. **RAPv5 and HRRRv4**models include additional forecast length extensions, improved methods of representing the water temperature of small lakes, more detailed information about the timing and intensity of thunderstorms and other severe weather threats, and the ability to more accurately predict amounts of cloud cover and precipitation in a timely manner. The length of RAP and HRRR forecasts are extended by 12 hours to 51 and 48 hours respectively. The updated models also will introduce new forecasting products for surface and upper-level smoke concentrations, a new hail size product, and several new parameters to help assess severe weather environments.	The operational RAP/HRRR model system (based on the Advanced Research Weather Research and Forecast dynamical core) provides significant improvements to forecasts for upper-air, surface, cloud and precipitation, and thunderstorms from the coordinated RAP and HRRR enhancements to the data assimilation, model physics, and post-processing formulations. The HRRR model, gridded at 3 km over the contiguous United States, makes it the highest spatial and temporal (hourly-updating) resolution forecast system run by NWS/NCEP. It assimilates many data sources including radar reflectivity and satellite data which provide critical details to weather forecasters in rapidly-changing and evolving weather events. Those forecasts in turn support emergency managers preparing and responding to severe weather impacts of all types, renewable energy generators making same day decisions, air traffic managers conducting aviation tactical and strategic planning, and wildfire managers making tactical firefighting decisions, and more.
High Resolution Rapid Refresh Data Assimilation System (HRRRDAS)	6/4/2019	12/2/2020	NWS/NCEP	NWS NCEP, NWS WFOs	The data assimilation system developed for the HRRR Ensemble, a 3-km 36-member data assimilation and forecast ensemble for a CONUS domain, transferred to NWS operations as part of the HRRRv4 implementation. Two of the key areas of development for HRRRDAS are the initialization of the convective scale ensemble and the maintenance ensemble spread during the data assimilation cycling. Both of these data assimilation system aspects are important for improving severe thunderstorm forecasts.	Hazardous weather events have the greatest impact when they are not accurately forecasted. The quest for advanced lead times of accurate forecasts has motivated the improvement of numerical weather prediction models. Stemming from successful hourly updated forecasting by the High Resolution Rapid Refresh (HRRR) model, the High Resolution Rapid Refresh Data Assimilation System (HRRRDAS) component utilizes ensemble data assimilation for improved convective scale forecasts. This new data assimilation component is singularly most important advancement in the HRRRv4 model. New observations for assimilation include: GOES-16 ABI radiances N20 CrIS-FSR/ATMS (with direct readout) GOES-16 AMVs TC vitals for trop cyclone location/strength Aircraft/raob moisture obs for p<300 hPa VIIRS/MODIS fire radiative power Assimilation Methods: HRRR - 3km ensemble DA (36 mems out to 1h) - HRRRDAS mean for HRRR IC and BEC
HRRR-Smoke model system	6/4/2019	12/2/2020	NWS/NCEP	NWS NCEP, NWS WFOs	The HRRR-Smoke air quality modeling system is based on the Weather Research and Forecasting (WRF) model coupled to chemistry. It was first deployed into NWS operations within the HRRRv4 model. HRRR-Smoke begins by parsing a stream of infrared satellite data from the VIIRS/JPSS satellite fire product in 3km resolution over the CONUS domain and looks for heat anomalies in the United States--fires that have erupted across the landscape. The HRRR-Smoke model is not relying on satellites to see exactly where the smoke is, just where these fires are. It relies on sophisticated weather models--changes in temperature, wind, water vapor, and precipitation--to project where the smoke will eventually end up. The forecast products of near-surface (up to 25 feet above the ground) and vertically integrated smoke concentrations (from the ground and beyond) are visualized on a GSL web-site in real time: http://rapidrefresh.noaa.gov/HRRRsmoke/.	Although the HRRR-Smoke model has been available experimentally since 2016, it just became operational as part of the HRRRv4 implementation by NWS. NOAA Incident Meteorologists (IMETs), Air Resource Advisors, and NWS San Francisco Bay Area/Monterey forecasters will use the HRRR-Smoke model to help advise the public about air quality and visibility issues caused by western U.S. wildfires. From the NWS AWC: "The NWS/Aviation Weather Center (AWC) is responsible for issuing AIRMETs and SIGMETs for smoke which include height, depth, and areal extent of smoke layers, visibility restrictions, and slantwise visibility...The advent into operations of HRRR smoke is a revolutionary advance in model guidance of smoke that should greatly improve AWC's AIRMET and SIGMET products."
Weather and Research Forecast Model-Chemistry: WRF-Chem v3.9 model WRF-Chem V4.0.2 model WRF-Chem v4.1 model WRF-Chem v4.2.2 model	 4/17/2017 11/9/2018 4/12/2019 1/15/2021	 4/17/2017 11/9/2018 4/12/2019 1/15/2021	WRF Research Applications Board and its committees via GitHub	International meteorological agencies, international and domestic research organizations	Since its initial release in 2000, the Weather Research and Forecasting (WRF) Model has become one of the world's most widely-used numerical weather prediction models. Designed to serve both research and operational needs, it has grown to offer a spectrum of options and capabilities for a wide range of applications. In addition, it underlies a number of tailored systems such as WRF-Chemistry (WRF-Chem) that are run with it as opposed to being stand-alone models run offline. Thus, the capabilities have strong two-way interaction with the atmospheric component. **WRF-Chem v3.9** improvements: 1) TUV photolysis option; 2) coupled WSM6 microphysics with MOZART gas wet scavenging; 3) Modified GOCART dust scheme for the SORGAM and MOSAIC chemistry options, and 4) A new trajectory option that calculates meteorological and chemical properties along air trajectories. **WRF-Chem v4.02:** Bug fixes **WRF-Chem v4.1**: Corrections to mapping of MEGAN emissions; Correction to dust and sea salt mass balance; and other improvements. **WRF-Chem v4.2.2**: Enable TUV diagnostics only for debugging (debug_level >=100). When using WRF-Chem with the new Photolysis option (phot_opt = 4) activated, the model spent too much time on looping and writing the TUV.diags which is only used for debugging photolysis rates.	GSL scientists are the leaders and caretakers of the WRF-Chem community code. Although the WRF-Chem model is not part of the NWS operational suite of models, it is used extensively by other meteorological services around the world. WRF-Chem is an international community-developed model with the Weather Research and Forecasting (WRF) model coupled with Chemistry. The model simulates the emission, transport, mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology. The model is used for investigation of regional-scale air quality, field program analysis, and cloud-scale interactions between clouds and chemistry. Integrating chemistry and atmospheric dynamics together at every time step makes WRF-Chem essential not only for investigating aerosol, weather, and climate interactions, but also for air quality research.

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NOAA Environmental Software Infrastructure and Interoperability - ESMF/NUOPC v7.1.0 Software Package	March 2018	March 2018	ESMF is publicly available software that can be downloaded from the web. It has been used in NWS operational models since 2008.	NWS, NASA, Navy, NWP modeling community. Used in NWS operational models since 2008.	The Earth System Modeling Framework (ESMF) is high performance, open source software for building and coupling Earth system models. ESMF is a community-developed package with a large and diverse customer base that includes modeling groups from the National Weather Service, the Department of Defense, NASA, NCAR, and other federal and international modeling centers. The National Unified Operational Prediction Capability (NUOPC) Layer defines conventions and templates for using ESMF, and makes it simpler to adopt the framework.	The wide adoption of ESMF and NUOPC Layer infrastructure means that centers can share components, transfer knowledge, and collaborate more closely. This results in better forecasts and better protection of life and property. New features in the v7.1.0 release of the ESMF/NUOPC Layer software include higher order conservative grid remapping, support for hierarchies of NUOPC Layer components, dynamic masking during sparse matrix multiplication, and piecewise remapping for high resolution grids.
Developmental Testbed Center (DTC): GSL Participation in Tests and Evaluations FY2016 FY2017 FY2018 FY2019 FY2020 FY2021	 April 2015 April 2016 April 2017 May 2018 May 2019 May 2020	 March 2016 March 2017 March 2018 April 2019 April 2020 April 2021	Transfer of reports/ knowledge from DTC to NWP modeling community, including NWS	NWP Modeling community NWS	**Tests and evaluations conducted:** **FY2016**: (1) Regional hybrid and ensemble-based data assimilation T&E using the Rapid Refresh (RAP) model; (2) T&E of replacement of Ferrier-Aligo with Thompson microphysical parameterization in the Hurricane Weather Research and Forecasting (HWRF) model; (3) Test of stochastic physics for regional ensemble using the Rapid Refresh (RAP) model, and (4) Test of impact of extending the the High-Resolution Rapid Refresh (HRRR) domain to better represent storm in the East and South coasts of the CONUS. **FY2017**: (1) High resolution (3 km) regional EnVar data assimilation testing and evaluation; (2) Stochastic parameter perturbations within the HRRRE (High Resolution Rapid Refresh Ensemble); (3) Testing and evaluation of smoothed terrain-following coordinate in WRF model; (4) Test and evaluation of Grell-Freitas convective scheme in Hurricane WRF (HWRF) model; (5) Test and evaluation of changes in the partial cloudiness parameterization in Hurricane WRF model; and (6) Test and evaluation of a modified cloud-overlap method in the radiation parameterization used in Hurricane WRF model. **FY2018**: (1 and 2) Addressing model uncertainty through stochastic parameter perturbations within the HRRR ensemble: Parts 1 and 2; (3)Testing and evaluation of new ARW development for use in RAP/HRRR models); (4)Testing data assimilation advancement in observation aspects and evaluation for operational readiness, and (5) Hurricane WRF model physics advancement. **FY2019**: (1) Testing and evaluation of new ARW development for use in RAP/HRRR models; (2) Test new observational capability (upgraded dual-polarized radar data) for high-impact convective systems using its high-resolution GSI EnVar framework; and (3) Review and test proposed GSI/EnKF code changes, and provide feedback and suggestions on code development. **FY2020**: (1) Report on the GSI-observer and JEDI-UFO differences for several major conventional observations (Quantify and evaluate the observation departure differences between JEDI-UFO and GSI-observer). and (2) Report on results of testing that will provide a baseline assessment of the performance of several physics suites at different model resolutions. **FY2021**: (1) Evaluation of Unified Forecast System (UFS) physics suites using the CCPP single column model and stand-alone regional configuration of the UFS-Atmosphere; (2) Testing and Evaluation of UFS Physics for Coupled Medium-range Weather and Subseasonal Forecasting--Report on the evaluation of GFS v16 retrospective runs and the investigation of using HDS to offer insight into GFS v17/GEFS v13; and (3) Performance of the RRFS baseline physics suite monitored through testing and evaluation as optimization/improvement continue.	The multi-agency Developmental Testbed Center (NOAA, NSF/NCAR, USAF) conducts major tests and evaluations of improvements to NWP forecast system components provided by the NWP research and operational communities. These tests and evaluations are critical for selecting proposed changes that need to be transitioned to operational centers. For example, they are critical for selection of the optimal physics packages, data assimilation strategies, and ensemble configurations used in the Hurricane Weather Research and Forecast (HWRF) model, the UFS Medium-Range Weather Application (including the operational Global Forecast System - GFS) and now in the UFS Short-Range Weather Application (including the Rapid Refresh Forecast System, RRFS, being developed by GSL and collaborators). GSL scientists are major participants in these tests and evaluations, providing subject matter expertise as well as management oversight.
HWRF 3.8a model public release/Users Guide HWRF 3.9a model public release/Users Guide HWRF 4.0a model public release/Users Guide (GSL participation within DTC)	11/21/2016 10/16/2017 11/5/2018	11/21/2016 10/16/2017 11/5/2018	DTC	Weather Research Community NWP Community	NWS Hurricane - Weather and Research Forecast (HWRF) code used in operations was made available to the public to obtain its innovative improvements to the code to improve weather forecasts.	Promoting faster and more frequent transition of research advances to operations ultimately increases the skill of the HWRF hurricane track and intensity forecasts. More accurate model guidance allows forecasters at the National Hurricane Center (NHC) to make better hurricane forecasts. These improved forecasts translate into more effective protection of lives and property at risk from hurricanes. They also make economic losses from unnecessary evacuations or over-forecasted threats less likely to occur. The DTC provides user and developer support for the Hurricane Weather Research and Forecasting (HWRF) model, conducts tests of HWRF using experimental configurations, and produces reports that evaluate the performance of these experimental configurations relative to the operational model. The DTC/GSL works closely with EMC to ensure that the HWRF code repository and the HWRF public release give users and developers access to the latest version of the operational HWRF model. The DTC also tests experimental configurations of HWRF that are being targeted by EMC for potential inclusion in the next version of the operational HWRF system.
HWRF Research to Operations Improvements (GSL participation within DTC) FY2016 FY2017 FY2018 FY2020	 10/01/2015 10/01/2016 10/01/2017 10/01/2019	 07/12/2016 08/02/2017 07/09/2018 08/05/2020	NWS/NCEP	Weather Modeling Community, NWS NCEP, NWS WFOs	**Innovative Improvements into operational HWRF:** **FY2016:** Updated partial cloudiness parameterization **FY2017:** Further updates to the partial cloudiness parameterization **FY2018:** 1) A new exponential cloud overlap method in the radiation parameterization, 2) Assimilation of Stepped Frequency Microwave Radiometer (SFMR) data, 3) Assimilation of Gulfstream-IV (G-IV) Tail Doppler Radar (TDR) data, 4) Assimilation of inner-core dropsonde measurements that account for dropsonde drift **FY2020:** A new exponential random cloud overlap method in the radiation parameterization	The Hurricane Weather Research and Forecast system (HWRF) is NOAA's flagship regional model for tropical cyclone prediction. The Developmental Testbed Center (DTC) serves as a neutral evaluator of new innovations from the research community that have the potential to improve HWRF forecasts. The DTC assists developers in adding their innovations to the HWRF codebase, and then tests and evaluates these innovations with input from the developers and the National Weather Service (NWS). The evaluation results are then shared with the developers and the NWS. If the NWS determines that an innovation provides sufficient forecast improvements, they will include the innovation in the next operational HWRF implementation. The research innovation can then contribute to improved forecasts of tropical cyclone track, intensity, structure, and precipitation, reducing loss of life and helping to protect property when tropical cyclones threaten.

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GSI v3.5 and EnKF v1.1 GSI v3.6 and EnKF v1.2 GSI v3.7 and EnKF v1.3 data assimilation code public release/Users Guide - Last official release (GSL participation within DTC)	7/31/2015 9/19/2017 11/7/2018	7/31/2015 9/19/2017 11/7/2018	DTC via NOAA VLab through GSI v3.6 and EnKF v1.2, then via Github repository	Weather Research Community NWP Community	GSI v3.7 and EnKF v1.3 are employed in the NWS data assimilation system for forecast models.	The Developmental Testbed Center (DTC) maintains and supports a community version of the EnKF system (currently Version 1.3) as well as the community version of the Gridpoint Statistical Interpolation (GSI) (now at Version 3.7). The testing and support of this EnKF system at the DTC includes both regional numerical weather prediction (NWP) applications coupled with the Weather Research and Forecasting (WRF) Model, as well as global NWP applications. With increased data assimilation research conducted using the operational GSI/EnKF, then there are more community researchers gaining extensive knowledge on the operational data assimilation system to provide innovative improvements. Those research results and knowledge can directly contribute to improve the operational data assimilation system and further improve the NWS weather forecasts to save lives and protect property.
Unified Post Processor (UPP) v3.1 Unified Post Processor (UPP v3.2 Unified Post Processor (UPP) v4.0 for WRF 4.0 public release/Users Guide Unified Post Processor (UPP) v4.1 Unified Post Processor (UPP) v9.0.0 (GSL participation with DTC)	5/5/2015 9/29/2017 3/19/2019 3/20/2020 5/1/2021	9/28/2017 12/13/2017 3/19/2019 3/31/2020 3/9/2021	DTC, via Github repository since 2020	Weather Research Community NWP Community	The UPP is used operationally for models maintained by NCEP. The UPP has the capability to post-process output from a variety of NWP models, including WRF-NMM, WRF-ARW, Non-hydrostatic Multi-scale Model on the B grid (NMMB), Global Forest System (GFS), and Climate Forecast System (CFS), and Finite-Volume Cubed Sphere (FV3). The DTC maintains a community version of the UPP code that aligns with what is used operationally at NCEP and prepares each upgrade for public release.	The Developmental Testbed Center (DTC) maintains a community version of the UPP code that aligns with what is used operationally at NCEP. Features and developments from NCEP are continually brought back into the community UPP package and likewise community members are encouraged to provide new features to DTC for proposal into operational code. The ability of the general research community to test innovations within a model framework identical to those run in the NCEP model suite is critical for effective R2O and implementation of innovations into operations. In addition, independent evaluation of testbed results through rigorous verification techniques allow the DTC to evaluate promising new model developments and physics parameterization modifications. Forecast improvements from these model innovations and modifications are vital to the continued safety of both lives and property. The build procedure and software dependencies have been updated to fit within the UFS software framework, to further align the community software with operational software, to help facilitate code management procedures.
Common Community Physics Package (CCPP) v1.0 Common Community Physics Package (CCPP) v2.0 Common Community Physics Package (CCPP) v3.0 Common Community Physics Package (CCPP) - Framework code Common Community Physics Package (CCPP) v4.0 Common Community Physics Package (CCPP) v4.1 Common Community Physics Package (CCPP) v5.0.0 (GSL participation within DTC)	4/8/2018 8/29/2018 6/17/2019 7/5/2019 3/16/2020 10/5/2020 3/8/2021	4/8/2018 8/29/2018 6/17/2019 7/5/2019 3/16/2020 10/5/2020 3/8/2021	Developmental Testbed Center via GitHub repository	Weather Modeling Community, NWS NCEP, NWS WFOs	As part of the Unified Forecast System (UFS), the Common Community Physics Package (CCPP) is designed to facilitate the implementation of physics innovations in state-of-the-art atmospheric models, the use of various models to develop physics, and the acceleration of transition of physics innovations into operational NOAA models. There are two distinct parts to the CCPP: a library of physical parameterizations (CCPP-Physics) that conforms to selected standards, and an infrastructure (CCPP-Framework) that enables connecting the physics to a host model. There is also a CCPP single-column model (CCPP SCM) which is a simplified framework that enables experimentation in a controlled setting using forcing datasets originating from experimental field campaigns. https://gsl.noaa.gov/news/common-community-physics-package-released-to-the-public The CCPP-physics contains the parameterizations and suites that are used operationally in the UFS Atmosphere, as well as parameterizations that are under development for possible transition to operations in the future. The CCPP-Framework code was incorporated into NWS/Environmental Modeling Center master codes for the UFS/Atmosphere, i.e. changes to the FV3, NEMS, and NEMSfv3gfs codes. EMC now exercises CCPP as part of its official regression tests. Goal is for all UFS applications to adopt the CCPP-Framework as part of their codes. The CCPP-Framework is scheduled for future NWS operations as a component of the GFSv17 model.	As a major improvement for the Unified Forecast System (UFS), the CCPP aims to support the broad community while benefiting from the weather research community. In such a CCPP ecosystem, the CCPP can be used not only by the operational centers to produce operational forecasts, but also by the research community to conduct investigation and development. Innovations created and effectively tested by the research community can be funneled back to the operational centers for further improvement of the operational forecasts. With the CCPP-Framework as part of the model codes released to the public, the CCPP can be used not only by the operational centers to produce operational forecasts, but also by the research community to conduct investigation and development. Innovations created and effectively tested by the research community can be funneled back to the operational centers for further improvement of the operational forecasts. The CCPP is used with the NOAA Unified Forecast System (UFS), which had its Medium-Range Weather Forecast Application publicly released on March 11, 2020. Community collaboration lowers the costs for the development and maintenance of the models, and results in more improvements and innovations to the code from multiple sources.
UFS Medium-Range Weather (MRW) Application v1.0 UFS Medium-Range Weather (MRW) Application v1.1 (GSL Participation within DTC)	3/11/2020 10/6/2020	3/11/2020 10/6/2020	DTC via GitHub repository	Weather Research Community UFS/NWP Community	This UFS Medium-Range Weather Application version 1.0 targets predictions of global atmospheric behavior out to two weeks. The software is distributed and maintained through GitHub, and the release of additional applications are planned in the coming year. Collaborating researchers can use the application in real-time, and promising research code will be considered for inclusion in future versions of the operational model. Future releases of model code will enable the research community to continue to advance them for operational use. NOAA and the modeling community also worked together to ensure the code is ready for use by students at the graduate level.	The outstanding work by GSL was acknowledged by former NOAA Administrator Neil Jacobs: "The entire UFS team deserves an immense amount of credit. Making global NWP user friendly is beyond challenging. A huge thanks to Dom Heinzeller for helping me debug my original build!" Other members of the GSL team: Ligia Bernardet, Curtis Alexander, Georg Grell, Mark Govett, Jennifer Mahoney. GSL/CIRES: Evan Kalina, Dom Heinzeller, Jeff Beck, Hannah Barnes, Cecelia DeLuca, Ming Hu, Man Zhang, Chris Harrop, Ed Hartnett, Xia Sun, Linlin Pan, and Dan Rosen.
GEFS-Aerosol Component/GSL-Chem	9/15/2019	9/23/2020	NWS/NCEP	NWS NCEP, NWS WFOs	The Global Ensemble Forecast System - Aerosols (GEFS-Aerosols) is an atmospheric composition model that integrates weather and air quality using the Finite Volume Cubed Sphere (FV3) core. The Global Systems Laboratory (GSL) led the project with other laboratories and NWS participants.	GEFS-Aerosols produces seven-day forecasts of the global distribution of some primary air pollutants: smoke, soot, organic carbon, sulfate, and large and small particles of dust and sea salt - collectively known as aerosols. Because these aerosols affect the weather, the model also provides weather forecasts. The new model is also capable of predicting the atmospheric impact of volcanic eruptions, which can disperse quantities of ash and other particulates over wide areas. The biomass burning plume rise module added in GEFS-Aerosols is from WRF-Chem, which is also used in the operational Rapid Refresh (RAP) v5 and High-Resolution Rapid Refresh (HRRR) v4 models making NWS one of the first major weather forecast centers to successfully implement any type of real-time forecasted aerosol into an already world-class-operational NWP model.

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UFS Short-Range Weather (SRW) Application v1.0 (GSL Participation within and outside of DTC)	12/1/2020	3/4/2021	DTC via GitHub repository	Weather Research Community UFS/NWP Community	With support from the Developmental Testbed Center (DTC), GSL released initial code for the Unified Forecast System Short-Range Weather Application (UFS SWA), the first iteration of the Rapid Refresh Forecast System/Limited Area Model (RRFS/LAM) based on FV3 dynamical core for convection-allowing model (CAM) applications to the weather modeling community for testing and research. The Unified Forecast System short-range weather application (UFS SWA) is the foundation of the RRFS/LAM, NOAA's future convection-allowing ensemble forecast system, which is the successor to the High-Resolution Rapid Refresh (HRRR) model.	The SRW Application is designed to be code that the research community can run, use for research, and commit any resulting innovation back to the relevant repositories. It is portable to a set of commonly used platforms. Specific configurations of the release (e.g. model resolutions, domain location, and physics options) are documented and supported.Interoperable atmospheric physics, along with the Noah Multi-parameterization (Noah MP) Land Surface Model options, are supported through the use of the Common Community Physics Package (CCPP). Atmospheric physics are a set of numerical methods describing small-scale processes such as clouds, turbulence, radiation, and their interactions. There are two physics options supported for the release. The first is an experimental physics suite being tested for use in the future operational implementation of the Rapid Refresh Forecast System (RRFS) planned for 2023, and the second is an updated version of the physics suite used in the operational Global Forecast System (GFS), v15.
Two Licensed Open Source Software Releases: Bayesian Processor Ensemble and Neural Network Microphysics (NN-MP)	5/27/2020	8/6/2020	GSL	General public Taiwan Central Weather Bureau	The Bayesian Processor Ensemble (BPE) is a statistical post-processing algorithm. BPE takes output from numerical weather prediction model forecasts, including ensembles, and produces calibrated posterior probabilistic forecasts. NN-MP is a neural network emulator of the Thompson microphysics code used in the NNMB and ARW WRF Numerical Weather Prediction (WNP) models.	The **Bayesian Processor Ensemble**algorithm was originally planned for use in the National Weather Service's National Blend of Models (NBM) but it was later decided not to include it. GSL made major contributions to the software implementation and testing of the algorithm. Software is released under a Creative Commons 0 Public Domain (open source) license for use by public. The Central Weather Bureau (CWB) of Taiwan is a user. The **Neural Network Microphysic**s software includes interfaces of the NN-MP code with the ARW WRF code, which is an open-source code in the public domain, with no restriction on its use. After further testing, the NN-MP code can replace the Thompson microphysics scheme in NWP models to provide significant savings in CPU time.
Ensemble Forecast Sensitivity to Observation Impact (EFSOI) tasks deployed in GFS v16.0.7	10/1/2020	3/22/2021	NWS/NCEP	NWS/EMC, NWP modeling community	GSL led implementation of additional tasks that work around the ensemble analysis system in GFS v16.0.7 but do not affect the main tasks in the NWS Global Forecast System (GFS). These tasks generate GFS ensemble forecasts of up to 30 hours and quantify the benefits of each measurement on forecasts from millions of observations that are assimilated into the GFS system every day. The information can help to quality control the observations as well as identify detrimental observations that contribute to forecast dropouts. GSL implemented ensemble forecast sensitivity to observation impact (EFSOI) formulations within the NCEP GFS v16 to estimate the observation impact at the analysis time. EFSOI of various types of data (e.g., in-situ, radiosonde, and satellite data) is quantified to help improve the forecasts associated with dropouts.	EFSOIs are used to understand the usefulness of observations and to diagnose the observation impact in models. Dropouts or low-skill forecasts in modern numerical weather predictions (NWP) occasionally appear for a short period of time (i.e., a few cycles or days). These poor forecasts can be the result of a multitude of factors. EFSOIs formulations in the model can help to identify observations that are detrimental to forecasts causing forecast dropouts and to quality control the observations.
Model Evaluation Tools (METplus) 2.2 Model Evaluation Tools (METplus) 3.0 Model Evaluation Tools (METplus) 3.1 (GSL participation within the DTC)	7/25/2019 7/26/2019 3/16/2020	7/25/2019 3/15/2020 8/11/2020	DTC, via GitHub repository beginning with v3.0	Weather Research Community NWP Community	GSL contributed to the migration of the Model Evaluation Tools Plus (METplus) code to Python 3 in v2.2, and to the implementation and execution of the METplus governance strategy, including hosting of code repositories on the dtcenter GitHub.	METplus is a verification framework that spans a wide range of temporal (warn-on-forecast to climate) and spatial (storm to global) scales. It is intended to be extensible through additional capability developed by the community. The core components of the framework include MET, the associated database and display systems called METviewer and METexpress, and a suite of Python wrappers to provide low-level automation and examples, also called use-cases.
METexpress v1.0 component of Model Evaluation Tools (METplus) METexpress v3.0.1 component of Model Evaluation Tools (METplus) METexpress v4.0.1 component of Model Evaluation Tools (METplus)	3/1/2019 4/1/2020 10/8/2020	3/31/2020 10/7/2020 3/31/2021	DTC via GitHub repository. GSL also deploys it using a cloud platform (Amazon Web Services)	NWS/EMC, NWP modeling community	METexpress is a model verification application used to assess new components and improvements to weather forecast models. It is a simplified visualization component of the enhanced Model Evaluation Tools (METplus) verification system. It is a new, more intuitive, web-based interface to the METViewer database that is easier to use for non-expert users. It is compatible with METplus and coordinates releases with METplus releases.	Verification software supports model development by producing the verification metrics (e.g. Equitable Threat Score, Mean Squared Error, etc.) necessary for critical assessment of proposed weather forecast model components and changes to weather forecast models. This global verification project developed a simplified, intuitive interactive interface to the Model Evaluation Tools (MET) database called METexpress, due to a need for a new interface that was more intuitive and easier to use in order to quickly view the most common plots for verification. NWS/Environmental Modeling Center managers indicated this would be very helpful for their model developers. The result provides a choice of web-based interfaces for users, one advanced (METviewer) and one quick-start (METexpress), each driven from the same database of verification data.
WRF hybrid vertical coordinate testing and evaluation (GSL participation within and outside of the DTC)	10/1/2016	4/17/2017 (WRFv3.9) and 7/12/2018 (HRRRv3)	NCAR/GSL	NCEP/NWS, Weather Research Community, NWP Community	A new, hybrid vertical coordinate was introduced in the WRF model, then tested both within the HRRR (GSL) and within extensive, controlled retrospective experiments of the RAP and HRRR (DTC). The hybrid coordinate allows for coordinate surfaces to gradually transition from sigma to isobaric levels with height, reducing the reflection of the terrain in the coordinate surfaces, and therefore minimizing the impacts of artificial noise on the prognostic fields.	Results showed that overall, the hybrid vertical coordinate produces the largest impact at upper levels, where the differences in coordinate surfaces are most pronounced due to the reflection of terrain over mountainous regions. As a result, wind speeds are generally improved near jet axes aloft. In addition, the depiction of vertical velocity at upper levels is greatly improved, with reduced spurious noise, and better correlation of vertical motion to forecast jet-like features. Upper-level temperature and relative humidity improvements were also found.
Coupled Unified Forecast System (UFS) Subseasonal to Seasonal Prototype 6 model (UFS S2Sp6)	2/19/2021	2/19/2021	UFS GitHub repository	NWS/EMC, Subseasonal to Seasonal (S2S) modeling community	GSL contributed to the improvement of the coupled UFS by implementing the fractional atmospheric landmask, which was adopted in its Prototype 6.	This treatment enhanced the coupling capability between the atmosphere and ocean/ice model, improved the air-sea interaction and better conserved global energy in the coupled UFS.

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Tech Transfer Project Name	Transition Start Date	Deployment Date	Deployment By	Deployment Beneficiaries	Description of What was Deployed	Impact/Feedback
DECISION SUPPORT						
FAA Aviation Weather Research Program (AWRP) Product Quality Assessments FY2016 FY2017 FY2018 FY2019 FY2020 FY2021	 10/1/2015 10/1/2016 10/1/2017 10/1/2018 10/1/2019 10/1/2021	 9/30/2016 9/30/2017 9/30/2018 9/30/2019 9/30/2020 9/30/2021	GSL transfer of knowledge in reports and presentations	-Federal Aviation Administration -NWS	GSL conducted the following quality assessments of aviation weather products/tools developed by other sources under the Federal Aviation Administration's Aviation Weather Research Program: **FY2016** 1) Offshore Precipitation Capability developed by MIT/Lincoln Lab;2) Graphical Turbulence Guidance Nowcast (GTG-N); 3) Forecast component of the Icing Product for Alaska (IPA-F) **FY2017** 1) CCFP (experimental CDM Convective Forecast Planning guidance) report; 2) Icing Product for Alaska - Diagnosis **FY2018** 1) Icing Product for Alaska - Diagnosis (completion); 2) Ensemble Prediction of Oceanic Convective Hazards (EPOCH); 3) Assessment of Ceiling and Visibility Analysis Products, Part 1; 4) Graphical Turbulence Guidance - Global Version, Part 1; **FY2019** 1) Assessment of Ceiling and Visibility Analysis Products, Part 2; 2) Graphical Turbulence Guidance - Global Version, Part 2; 3) Ensemble Prediction of Oceanic Convective Hazards (EPOCH) Part 2; 4) Offshore Precipitation Capability (OPC) Assessment; 5) Comparison of Graphical Turbulence Guidance CONUS Version 3 Vs Global **FY2020** 1) Icing Product Alaska--Forecast (IPA-F) Implementation Assessment; 2) Rapid Refresh (RAP) Model Version 5 Assessment; 3) High-Resolution Rapid Refresh (HRRR) Model Version 4 Impact Assessment. **FY2021** 1) Convective Weather Avoidance Model (CWAM); 2) The Visibility Estimation through Image Analytics (VEIA); 3) the Offshore Precipitation Capability (OPC), satellite-based lightning detection; and 4) the OPC, west coast expansion.	GSL provides independent scientific assessments of weather research products developed by other sources (e.g. MIT/Lincoln Labs, NCAR, etc.) through the Federal Aviation Administration's Aviation Weather Research Program. The assessments ensure that the products and tools are scientifically accurate and provide value to the individual decision-maker within their operational aviation decision processes. They benefit the FAA AWRP which uses assessment results as part of the decision process to advance a product to the next step in the R2O process; product developers use assessment results to identify needed product improvements; and product end-users (e.g. NWS forecasters) can use assessments to understand the strengths and weaknesses of the products they use. The FAA, airlines, and general aviation pilots are then able to use weather information from the products that they have more confidence in. Ultimately this research and resulting product assessments increase the safety of aviation and the national air space.
AWIPS II Ensemble Tool in AWIPS OB 17.3.1	8/31/2017	4/10/2018	NWS	NWS WFOs	The AWIPS-II Ensemble Tool was developed to help forecasters assess and communicate uncertainty in their forecasts and improve decision support services for their customers. The tool provides quantitative information about the probabilities an event will occur. This tool enables forecasters to provide clients with individualized decision support for assessing hazard contingencies in terms of the most likely scenario, most dangerous scenario, and possible extent or scale of the impacts (cities, transportation, critical national infrastructure). It also evaluates a wide range of emerging national, local, and regional threats using a nearly continuously updated ensemble of predictive numerical weather guidance (200+ predictions per day).	Ensemble model information greatly helps advance the communication of probabilistic and uncertainty information to customers. Using the ensemble information and capabilities at the local office enhances the current deterministic forecast and develops new ways of expressing uncertainty in the forecast, particularly for high-impact events.
AWIPS Hazard Services Watch/Warnings/Advisories Applications: Hazard Services v1.0 Hydrology-Initial Operating Capability (Hydro-IOC)	3/2019	12/2019	NWS AWIPS	NWS/WFOs	Hazard Services is a major enhancement that will ultimately replace all watch, warning, and advisory generation software in AWIPS. The purpose is to consolidate, re-design and re-implement the AWIPS hazard services tools using the best science available while optimizing them for performance. Hazard Services v1.0 (Hydrology-Initial Operating Capability) software code for watches, warnings, and advisories for flooding and flash flooding was handed-off to NWS for limited operations prior to later nationwide deployment in AWIPS Operational Build 19.3.1.	AWIPS applications WarnGen, Graphical Hazards Generator (GHG), and RiverPro assist forecasters to produce hazard watch, warning, and advisory products and deliver services. These applications are critical to WFO operations, demanding high performance and dependability at times of high usage. While capable, the applications are difficult to operate, maintain, and adapt to the evolving digital forecast paradigm; new tools are needed to meet these operational challenges. The goal of Hazard Services is to unify the three current applications into one improved hazardous weather forecast application and add new functionalities to enable the public and NWS partners to make timelier and better-informed decisions in advance of expected hazards. Four Hazard Services software packages are being developed by GSL for deployment by NWS through 2023. Functional Forecaster Assessment Tests (FFAT) of the applications are conducted with NWS forecasters to ensure their needs are met and to receive feedback for making improvements to the software.
AWIPS Hazard Services Watch/Warnings/Advisories Applications: Hazard Services v2.0 Winter Weather, Hydrology Hazard Simplification, Common Alerting Protocol (CAP)	9/01/2020	Winter Weather activated at Limited WFOs - Sept 2020 Winter Weather activated at all WFOs - Summer 2022 Hydrology Hazard Simplification scheduled activation Summer 2021 Common Alerting Protocol scheduled activation Fall 2021	NWS AWIPS	NWS/WFOs	Hazard Services v2 incorporation into NWS AWIPS OB 20.2.1 which includes Winter Weather and Hydrology Hazard Simplification plus the Common Alerting Protocol (CAP) formatter. Operational Builds (OB) deployments were delayed due to pandemic.	
AWIPS Hazard Services Watch/Warnings/Advisories Applications: Hazard Services v3.0 Non-Precipitation Weather (NPW) Hazards, NPW Hazard Simplification, and Common Alerting Protocol (CAP) messages for NPW hazards	01/04/2021	Non-Precipitation Weather activated at limited WFOs - January 2021 Non-Precipitation Weather nationwide scheduled activation - Winter 2021/2022	NWS AWIPS	NWS/WFOs	Hazard Services Version 3 contains enhancements to the long-duration hazard product creation workflow and the ability to issue operational Non-Precipitation Weather hazard products. These components were spread across two AWIPS check-in periods (OB21.3.1 and OB21.4.1). Around 15 NWS offices had access to these improvements early through an AWIPS Test Authorization Note (ATAN) #1242, which allowed for the first operational issuance of Winter Weather and Non-Precipitation Weather hazards through Hazard Services in the Winter/Spring 2021 season. GSL collected feedback on their progress and incorporated their suggested enhancements into the Version 3 release.	

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Advanced Technologies						
GPS-Meteorology (GPS-Met)	10/1/2015	9/1/2016	Data from GPS Solutions, Inc., and deployed by NWS	Earth Networks Inc, (contractor) and GPS Solutions (subcontractor) NOAA: NWS/NCEP and NESDIS	GSL GPS-Meteorology's data processing system using ground-based Global Positioning Satellite (GPS) receivers collected data that estimate atmospheric water vapor/precipitable water and are used in NWS operational models and NESDIS Total Precipitable Water product and algorithms. GSL (formerly Global Systems Division) had been producing these data in a pseudo-operational role since 2002 and NWS had been using the data operationally since 2005. GPS-Met system functionality was transferred to private industry through a CRADA (Cooperative Research and Development Agreement) enabling commercial vendors to provide GPS-Met data that meet quality standards to NWS and NESDIS through a data buy starting September 1, 2016.	The transition of GPS-Met technology to the private sector using the CRADA fulfilled a stated goal under the "Lab to Market Cross Agency Priority Goal" to increase the impact of Federally-funded research and development through transfers to commercial markets. GPS Solutions, Inc. is now paid by the NWS for the GPS-Met data.
Meteorological Assimilation Data Ingest System (MADIS) - Software for NWS MADIS v2.1.4 and v2.1.5 MADIS v2.1.5.10 MADIS v2.2 MADIS v3.0	 1/2016 5/1/2017 10/1/2018 5/31/2020	 11/2016 10/30/2017 9/15/2019 Pending	NWS/NCEP Central Operations/IDP	NWS/NCEP, NWS/WFOs, State DOTs, organizations/companies providing observations to MADIS, universities, airlines, ground transportation, and other private sector users	**MADIS v2.1.4**incorporates the NWS Automated Flood and Warning System observations **MADIS v2.1.5**incorporates 1) Clarus system capability from the U.S. Federal Highways Administration, 2) NWS Hydrometeorological Automated Data System (HADS), and 3) USDA's Snow Telemetry and Snow Course Data and Products. **MADIS v2.1.5.10** contains 1) New real-time display of aircraft water vapor sensor system (WVSS-II) for the public, 2) New sites for HADS; 3) SNOTEL updates/changes; and 4) Mesonets for Nebraska and State of New York. **MADIS v2.2**enables 1) direct ingest of aircraft-based meteorological observations into MADIS which is designated as the World Meteorological Organization's Global Data Centre (GDC) for Aircraft Based Observations (ABO), 2) ability to handle Clarus QC, 3) updates and site additions to HADS, 4)5 new AFWS providers, 12 new National Mesonet providers, 8 new or updated Road Weather Information System (state DOTs) providers, and 5) improvements to the API and graphical displays. **MADIS v3.0**delivers an operating system upgrade to RHEL-7; database upgrade to PostgreSQL 10, and Java JDK upgrade to 1.8.	MADIS fills gaps in NOAA's observational infrastructure, GSL MADIS partnered with non-NOAA entities to acquire environmental observations from their networks, integrate their observations with NOAA's, quality control the observations, and provide a standardized interface for delivering this information to NOAA operations and the greater meteorological community. MADIS' centralized data acquisition and delivery system reduces the cost of operations for NWS Weather Forecast Offices, which would otherwise be required to individually, and often redundantly, collect observations locally. By assimilating private sector as well as government purchased observations, MADIS saves NOAA the costs of new observing systems and the cost of maintenance for these systems. MADIS attained operational status at NWS in January 2015. The MADIS observations are used to improve NWS numerical weather prediction models by helping to better initialize weather models at NWS for a better forecast, particularly for severe and hazardous weather. NWS forecasters use MADIS data to help with there forecasting efforts for severe weather events. MADIS data is also used for verification of NWP models. Through software packages, GSL MADIS continues to enlarge and enhance operational NWS MADIS.
Science On a Sphere® software releases SOS v5.1 SOS v5.2 SOS v5.3 SOS v5.4 SOS v5.5	 July 2016 April 2017 January 2018 October 2018 September 2019	 August 2016 May 2017 February 2018 November 2018 October 2019	SOS purchasers and clients	SOS customers; SOS Users Collaborative Network	**SOS v5.1**- New version of SOS operating system with fully featured version of the Visual Playlist Editor and custom datasets that are searchable on an iPad, increasing the ease of use by presenters. **SOS v5.2**- Enhancements included text PIPs, improvements to Visual Playlist Editor, new layer control on iPad, projector control utility, and rewritten documentation. **SOS v5.3**- Improves software security, better playback of videos, featured and timely datasets that automatically sync to all sites, better installation process, and a new high resolution library. **SOS v5.4**- Includes new features, enhancements, and fixes in several applications across the SOS application suite. **SOS v5.5**- includes updating the operating system to improve configuration and project controls	Science On a Sphere® (SOS) is a room-sized global display system that uses computers and video projectors to display planetary data on a six-foot diameter sphere to help illustrate earth system science to people of all ages. NOAA has been spreading data and scientific literacy worldwide with SOS for nearly two decades with real-time and archived weather, climate, land use, ocean, and space environmental datasets.The SOS team releases new versions of the SOS software regularly to its customers to enhance the visualizations, increase ease of use, incorporate new technologies, and make sure that it is compatible with the latest hardware.
SOS Explorer (SOSx®) software releases SOSx® v1.1 SOSx® v1.2 and v1.3 SOSx® v1.4 and v1.4.1	 August 2016 February 2017 November 2017	 September 2016 May 2017 May 2018	SOS Explorer (SOSx®) purchasers and clients	SOS Explorer customers SOS Users Collaborative Network	**SOSx® v1.1**- Provides 1) Easy to use touchscreen interface for maximum interactivity; 2) Over 100 datasets, including real-time datasets with descriptions; 3) Educational videos linked to specific datasets for deeper inquiry; 4) Tours that create a narrative through the datasets and help users make connections; 5) Tour builder application that allows sites to make their own narratives through relevant datasets; 6) Analysis tools to easily measure, probe, and plot data from the visualizations: 7) Stunning graphics in beautiful 4K resolution; and 8) SOS website interactivity for choosing best fit datasets at each site **SOSx® v1.2**- Includes many new features that make deploying SOSx® to new sites even easier and allows for a variety of configuration set ups. **SOSx® v1.3**- Added new Tourbuilder improvements so each site can spice up their own exhibits to best fit their location, and added new 3D content to the library including Aurora 3D, Saturn with Rings, Humpback Whale Migration, and Satellite Models - Real-time. **SOSx® v1.4**- The virtual reality feature is fully supported; ways to localize and personalize the exhibit for individual sites to improve the customization capabilities including more language support. **SOSx® 1.4.1**- An auto-upgrade feature for your SOSx® version will activate upon start-up if it is out of date. Also included are some new animal migration datasets including a humpback whale, a loggerhead sea turtle and a great white shark.	Created in September 2016, SOS Explorer (SOSx®) is a flat screen version of Science On a Sphere® (SOS). The revolutionary software takes SOS datasets, usually only seen on a 6-foot sphere in large museum spaces, and makes them more accessible, portable, and interactive on a desktop or laptop computer and displayed on a large monitor or projection screen for K-12 students in classrooms. Animated images such as atmospheric storms, climate change, and ocean temperature can be shown in SOSx®, which explains sometimes complex environmental processes in a way that is simultaneously intuitive and captivating. GSL's Science on a Sphere (SOS) Explorer and SOS Explorer Mobile are the 2020 recipient of the Impact Award from the Federal Laboratory Consortium (FLC) for Technology Transfer.
SOS Explorer Mobile App public release	8/1/2019	8/1/2019 4/15/2021 Update	GSL to the public	General public, teachers, students	SOS Explorer® Mobile (SOSx® Mobile) is a mobile app version of SOSx®, freely available to the public for download, that allows users to explore 115 SOS datasets and learn more from NOAA, NASA, and academic institutions.	The Science On a Sphere Explorer™ mobile app has been downloaded over 25,000 times. “I use my phone to show sea surface currents, clouds, Saturn's rings, and much more to anyone who will let me,” said Kate Semmens, science director at Nurture Nature Center, an Easton, Pennsylvania science museum. “It's a great way to work with teachers and students.” The preparing of the visual tours on the mobile app have been a great collaboration between different NOAA offices. For example: Tour - Monster Saharan Dust Plume" was a collaboration with Atlantic Oceanic and Meteorological Laboratory (AOML). The GSL Finite-Volume Cubed Sphere - Chemistry (FV3 Chem) - Saharan Air Layer is another tour that uses a National Environmental Satellite, Data, and Information Service (NESDIS) video and GOES imagery provided by the NESDIS Viz Lab.

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Science On a Sphere® (SOS) Exhibit Installations FY2016 - 13 Installations FY2017 - 8 installations FY2018 - 11 installations FY2019 - 11 installations FY2020 - 6 installations FY2021 - 2 installations	 1/1/2016 10/1/2016 10/1/2017 10/1/2018 10/1/2019 10/1/2020	 9/30/2016 9/30/2017 9/30/2018 9/30/2019 9/30/2020 9/30/2021	SOS purchasers and clients	NOAA Office of Education K-12 students and teachers The general public, The SOS Users Collaborative Network, Science museums Universities	Considered instrumental for NOAA public education and outreach, Science On a Sphere® (SOS) is a room-sized global display system that uses computers and video projectors to display planetary data on a six-foot diameter sphere to help illustrate Earth system science to people of all ages. Exhibits of SOS can be found in science museums, history museums, universities, visitor centers, aquariums, and many other public educational venues.	The captivating SOS display is in demand by science centers, museums, universities, schools, science conferences, and other venues. SOS improves the public's scientific knowledge about the Earth system and displays NOAA's data, operations and research in a compelling way for the public. Facts: 1) Over 500 datasets available for showing, 2) 177 SOS installations worldwide, 3) SOS exhibits in 33 states and 23 countries including Mexico, China, India, Brazil, Korea, Macau, Indonesia and Saudi Arabia, 4) An estimated 67 million viewers each year, and 5) Over 250 members in the SOS Users Collaborative Network which meets every two years. 1/20/2021 Letter - Tim Gallaudet, Ph.D., Rear Admiral, U.S. Navy (Ret.), Assistant Secretary of Commerce for Oceans and Atmosphere /Deputy NOAA Administrator, "Because of NOAA's ability to provide real-time data and to continuously evolve the technology and support a user network, there is a significant commercial market built around NOAA's SOS program. The SOS data catalog has tremendous value for the private sector as well as our education partners. NOAA's name gives the datasets a stamp of authenticity that is highly marketable. The other, commercial sphere- display companies use the SOS data catalog and have built their systems to be compatible with these data sets. Planetarium companies also market that they offer the SOS data catalog."