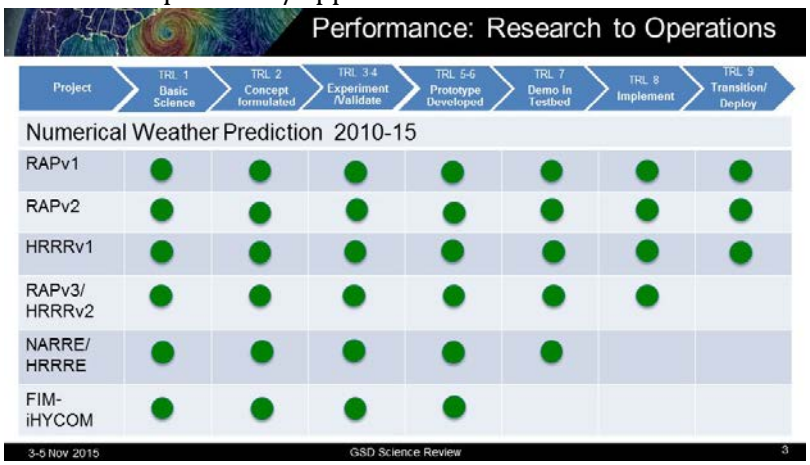
D. Research to Operations and Applications

GSD's research and development supports the NOAA goal of a Weather-Ready Nation as well as the NOAA objectives for an integrated environmental modeling system, accurate and reliable data from sustained and integrated earth observing systems, and a holistic understanding of the Earth system through research. GSD complies with NOAA's Annual Guidance Memorandum to accelerate the transition of research advances to applications. The recipients of our R&D products, services, and information include public, private and academic organizations who apply our research to make better operational decisions supporting various societal and economic sectors. GSD's applications research is utilized by its operational recipients to improve the following:

- life, property, and natural resources protection during severe weather
- emergency management and disaster preparedness such as evacuations
- disaster response and resiliency of communities
- efficiency of renewable energy generation and use
- air traffic efficiency and passenger safety
- safety and efficiency of surface transportation
- atmospheric aerosols prediction such as wildfire smoke, dust, and volcanic ash which can affect weather,
- physical science education and outreach at all age levels, particularly K-12

Numerical Weather Prediction (NWP)

Research to Operations/Applications – Transition Readiness Level



Key:
RAP – Rapid Refresh Model
HRRR – High Resolution Rapid Refresh
NARRE – North American Rapid Refresh Ensemble
HRRRE – High Resolution Rapid Refresh Ensemble
FIM – Flow-following finite-volume Icosahedral Model
iHYCOM – Icosahedral Hybrid Coordinate Ocean Model

A summary of the numerical modeling technologies and an assessment of their significance/impact on operations is provided here.

Regional Modeling

Our nation increasingly needs detailed, reliable, quickly-updated weather guidance to enable the commerce and transportation that drive US economic activity and the warnings that save citizens' lives and increase public safety. GSD has developed weather models covering North America that provide frequently updated short-range weather forecasts primarily for the severe weather forecasting and U.S. aviation communities, but increasingly critical for the renewable energy generation industry as well.

1. Rapid Refresh (RAP) Model

Research Description: The Federal Aviation Administration (FAA) needed faster updates to weather forecasts at higher resolutions to support both the commercial and civil aviation communities, particularly at airports for takeoff and landings. Through the FAA's Aviation Weather Research Program (AWRP), resources were provided to GSD to develop an hourly-updated regional model at 13-km resolution which would cover North America and replace the Rapid Update Cycle model running at 13-km resolution over CONUS. The RAP uses a community numerical forecast model (WRF-ARW) and analysis/assimilation system (GSI; Gridpoint Statistical Interpolation) components to initialize the model. In the RAP model, GSD implemented innovations for radar reflectivity, cloud, and surface data assimilation options to GSI that are also available for other models. GSD has also developed improved parameterizations of boundary-layer mixing, convective clouds, and land-surface (soil, snow, vegetation) processes with the Weather Research and Forecasting (WRF) community model to improve RAP forecasts but also has made them available to all WRF users. For further information, visit http://rapidrefresh.noaa.gov/.

Research to Applications: On May 1, 2012, the 13-km Rapid Refresh Model (RAP) became operational at NWS/NCEP. The RAP replaced the previous RUC (Rapid Update Cycle) model and expanded coverage from CONUS to North America, including Alaska. RAPv2 was implemented at NCEP in Febuary 2014, and RAPv3, with further improvements to storm environment, cloud, and winter-storm fields, is planned for NCEP in February2016. The RAP is the parent model for the 3-km High-Resolution Rapid Refresh (HRRR) model providing boundary layer conditions for HRRR initialization.

2. High-Resolution Rapid Refresh (HRRR) Model

Research Description: With support again from the FAA for even higher resolutions for airport terminal weather forecasts, GSD developed the High-Resolution Rapid Refresh (HRRR) model. The HRRR provides a significant new capability in severe weather prediction for NWS. With the HRRR, GSD scientists merged advances in weather prediction science and high performance computing technology with a new breakthrough technique for using radar data to achieve a new standard process for up-to-the-minute weather forecasting at a 3-km scale. For further information, visit http://rapidrefresh.noaa.gov/hrrr/.

Research to Applications: The HRRR model went operational at NWS in September, 2014. Its impact was immediate, delivering forecasts, in high detail, of critical weather events such as severe thunderstorms, flash flooding, and localized bands of heavy winter precipitation. Since the HRRR is run hourly and assimilates many data sources including radar reflectivity data, the HRRR helps provides critical details to forecasters in rapidly-changing and evolving weather events. For more information, visit http://www.noaanews.noaa.gov/stories2014/20140930_hrrr.html. HRRRv2 is planned for operational implementation also in February 2016.

The RAP and the HRRR produce hourly weather forecast updates that support decision making. Air traffic controllers depend on the forecasts to direct air traffic around rapidly developing hazardous weather and emergency managers use them to prepare for potential national disasters that threaten property and lives. The U.S. energy sector relies on the RAP/HRRR to help them improve the efficiency and effectiveness of wind and solar energy production. Wildfire managers use the forecasts to help tactical firefighting decisions.

3. WRF-Chem Model

Research Description: GSD leads the global community development of WRF-Chem, a next-generation coupled weather/air quality numerical prediction system based on the WRF model. Gas-phase chemistry and aerosol processes are tightly coupled to meteorology within the WRF model structure. WRF-Chem has a large international user base. GSD currently runs experimental online chemistry versions for many of its models, including RAP-Chem, HRRR-Smoke, and FIM-Chem. These higher-resolution experimental models are used to predict weather, dispersion, and air quality, including predictions of dust, smoke and volcanic ash dispersion and also support other weather, climate, and air chemistry research experiments, e.g. SENEX 2013 (Studying the Interactions between Natural and Anthropogenic Emissions at the Nexus of Climate Change and Air Quality) and FRAPPE (Front Range Air Pollution and Photochemistry Experiment). For further information about WRF-Chem, visit http://ruc.noaa.gov/wrf/WG11/.

Research to Applications: The WRF-Chem model was used operationally by the U.S. Air Force until recently but continues to be used operationally by many forecasting centers in other countries. For a list of some of the countries using WRF-Chem, visit http://ruc.noaa.gov/wrf/WG11/Real_time_forecasts.htm.

4. Ensembles at Regional Scales

Research Description: Current ensemble guidance provided by NWS comes from the Short Range Ensemble Forecast (SREF), updated every 6 hours at a 16-km resolution. But transportation providers (particularly air traffic managers), emergency managers, and the renewable energy providers want enhanced, higher-resolution (both temporal and spatial) regional ensemble guidance that provides more forecast uncertainty or probabilistic information, especially about severe weather. The idea is to have SREF continuing to run on 6-hourly cycles out to 84 forecast hours with GSD's and NCEP's North American Rapid Refresh Ensemble (NARRE) members as a subset updating hourly at 12-km grid spacing and running out to 18-24 forecast hours. Having these members as a subset of SREF means that the model uncertainty, at least at the beginning, will be addressed by use of two dynamic cores ARW (RAP) and NAM (NMMB) and variations in physics.

Next will be to transition the NARRE to the High Resolution Rapid Refresh Ensemble (HRRRE) to provide 3-km, hourly forecast guidance.

The HRRRE system will build upon a prototype time-lagged ensemble package that has been running since June 2009 producing a real-time, experimental probabilistic thunderstorm guidance product. The existing HRRR Convective Probability Forecast (HCPF) algorithms will serve as a starting point for the creation of the new Automated High-Resolution Ensemble-Based Hazard Detection Guidance Tools. The development will also leverage the previous ensemble generation work of the NCEP/EMC group and NCAR and to collaborate on best methods for creating these hazard guidance tools using time-lagged ensembles from the 3-km, hourly-updated HRRR model. A direct outcome of the project will be improved ensemble hazard guidance tools for operational forecasters that will reduce the ensemble information overload problem and enable a more efficient and accurate characterization of forecast uncertainty.

Research to Applications: GSD is working with the NWS/EMC and the Developmental Testbed Center (DTC) to develop the NARRE as an hourly-updated ensemble related to the current 6 member SREF now running at NCEP. According to the EMC roadmap, the new 6-member NARRE is scheduled for operational implementation in 2017. Currently, a preliminary time-lagged version of NARRE using multiple RAP members initialized at different times is running at NCEP. After 2017, the next implementation will be for the HRRRE to provide 3-km, hourly-updated probabilistic forecast guidance. An experimental HRRRE has been running in real time, producing thunderstorm probability grids which have been delivered to the Aviation Weather Center (AWC) and Storm Prediction Center (SPC) for the last 3 years. Over the next three years the work will advance to enable a transition of HRRRE (or High-Resolution Ensemble Forecast –HREF) to operations in 2019. The Automated High-Resolution Ensemble-Base Hazard Detection Guidance tools being developed by GSD using the HRRRE will then be available to operational forecasters.

5. Hazardous Weather System for U.S. Space Centers

Research Description: Operations at U.S space centers are heavily impacted by severe weather conditions and windstorm forecasts. Safety regulations restrict work on tall gantries, shuttle transport, refueling, and other operations during high wind events. Winds may also impact safety following rocket blasts, fuel spills, and other accidents by carrying toxins from an accident zone farther afield. Beginning in FY2003, NOAA ESRL/GSD developed and implemented a state-of-the-art analysis, forecast, product generation, and display system as part of the U.S. Air Force's Range Standardization and Automation (RSA) program.

Research to Applications: Since FY2003, GSD continues to maintain and update the RSA weather forecasting system. The data management, processing, and display modules are based on the National Weather Service's Advanced Weather Interactive Processing System (AWIPS-I) and eventually will be transitioned to AWIPS-II. The Local Analysis and Prediction System (LAPS), also developed at GSD, is used to analyze the current weather and then initialize a local model running in three nested domains with horizontal grid resolutions of 10, 3.3, and 1.1 km. In FY2015, the local model was replaced with the Weather Research and Forecasting Model (WRF)/Advanced Research WRF (WRF-ARW). This modeling system is widely used around the world to provide weather

guidance to supplement NOAA models including HRRR, RAP, and GFS. In addition, GSD provides system upgrades to improve Launch Weather Officers' effectiveness and efficiency.

6. Local Analysis and Prediction System (LAPS)

Research Description: GSD provides the Local Analysis and Prediction System (LAPS) to more than 150 group and individual users in support of data assimilation, nowcasting, and mesoscale model initialization and post-processing. The LAPS user base has historically included federal agencies, state agencies, private entities, academic institutions, and international agencies. LAPS is a highly portable system with adjustable horizontal, vertical, and temporal resolution that runs on inexpensive hardware (including desktops and laptops), providing the capability to blend a wide variety of global, national, and local datasets into analyzed grids. LAPS benefits forecasters, decision makers, and researchers with high-resolution frequently updated weather information for a wide variety of settings.

Research to Applications: In FY2014, LAPS was implemented into the AWIPS II basic suite of forecasting tools because NWS Weather Forecasting Offices continue to need it for very high resolution nowcasting, particularly in complex terrain. GSD is now collaborating with NWS in an effort to use GSI data assimilation and HRRR forecast model to provide nowcasting 3-D cloud/wind/temperature grids (Rapidly Updating Analysis - RUA) to replace LAPS for NWS and other agencies.

7. Modeling Support for R&D Testbeds

Research Description: GSD supports a number of NOAA research-to-applications testbed activities with high-resolution experimental model guidance and advanced data assimilation to meet the needs of the testbed experiments and product transition to operations. Over the past five years, GSD researchers participated in and contributed to the following testbeds and experiments:

- Hydrometeorological Testbed (HMT) in collaboration with ESRL/PSD using the Experimental Regional Ensemble Forecast System (ExREF) up to winter 2013-14 and then switching to NARRE for winter 2014-15

- Hazardous Weather Testbed (HWT) in collaboration with NSSL, NCEP/SPC and the NWS forecast office in Norman, OK: Spring Experiment/Warning and Forecasting Programs using the RAP and HRRR with 3 to 6 GSD participants for a week every spring for the past 15 years; Participation in Forecasting a Continuum of Environmental Threats (FACETs) planned for 2016.

- Aviation Weather Testbed (AWT) in collaboration with NCEP/AWC using experimental RAP and HRRR; one or two GSD participants for a week in Kansas City every summer since inception.

- Climate Testbed (CTB) to design possible ensemble guidance for improved sub-seasonal forecasting including use of GSD's FIM-iHYCOM coupled model.

- GOES-R Testbed to improve use of GOES-R products in the RAP and HRRR models.

- Flash Flood and Intense Rainfall (FFaIR) in collaboration with the NCEP/WPC and NSSL using the HRRR (NCEP and experimental); one or two GSD participants for a week every summer at the WPC since inception.

- Winter Weather Experiment (WWE) in collaboration with HMT and NCEP/WPC using the RAP, HRRR, and prototype NARRE; one or two participants for a week at the WPC every winter since inception

Research to Applications: In these testbed activities NWS operational units are given the opportunity to use advanced experimental products in their operations and developers have opportunity to gain familiarity with operational challenges. This interaction between developers and operational forecasters and the feedback to developers regarding product performance has proven very valuable over the years. Products tested during these exercises are given a rigorous evaluation and increases the likelihood that they will be incorporated into NWS operations.

Next Generation Global Modeling

NOAA seeks to accelerate improvements in the skill of U.S. operational global numerical weather prediction systems which can provide more accurate, longer lead-time forecasts. Having a reliable and skillful forecast, especially in the case of high-impact weather events such as hurricanes, would enable better decision-making to save lives and property. In addition to improving the current generation of hydrostatic global models and ensemble products from them, NOAA is accelerating the development of the next generation of non-hydrostatic, cloud-resolving global models for medium range forecasts for the Next Generation Global Prediction System (NGGPS). These models are expected to provide a quantum-leap forward in the Nation's forecast skill by the end of this decade.

1. High Impact Weather Prediction Project (HIWPP)

Research Description: Funded by the Disaster Relief Act of 2013 in the aftermath of Superstorm Sandy, HIWPP was a cross-NOAA effort with several goals. GSD participated to 1) Test next-generation global weather models in a real-time running mode; 2) Evaluate the North American Multi-Model Ensembles' ability to improve forecasts out to months and use cutting-edge visualization technology; and 3) Partner with the broader weather community to assess research models in realtime. For the first goal, GSD used its expert researchers and high performance computing resources to conduct a comparison of the dynamical cores from four experimental global models provided by NWS/EMC, OAR/GSD, OAR/GFDL, and NSF/NCAR. For the second goal, GSD provided results from the Flow-following Finite Volume Icosahedral Model (FIM) using the NOAA Earth Information System (NEIS) visualizations to evaluate the model data. The third goal was addressed through the HIWPP Open Data Initiative where members of the modeling community could access model results and provide input. http://hiwpp.noaa.gov/

Research to Applications: In July 2015, GSD provided the report the NWS used to down-select two of the model cores to consider for operational development for the NGGPS. Although the GSD

global model dynamical core was not selected, GSD will continue to play a central role in transitioning an experimental global weather model to operations due to its past successes transitioning models to NWS operations. HIWPP also implemented an Open Data Initiative providing experimental real-time global forecast data to the community or anyone who wants the model codes and data.

2. Flow-following Finite-volume Icosahedral Model (FIM)

Research Description: With the advent of distributed-memory computing late in the last century, it was recognized that, because of poor scaling with the spectral approach, alternative architectures for global models were going to become necessary. Both Louis Uccellini (now head of the National Weather Service) and Professor Don Johnson of the University of Wisconsin encouraged GSD to develop a global version of a model with an isentropic coordinate, following GSD's successful use of the Rapid Update Cycle (RUC) hybrid-isentropic model for regional forecasting. As a result, ESRL Director Sandy MacDonald, Dr. Jin Lee and others in GSD designed and coded a shallow-water model on an icosahedral grid in the early 2000s, and in 2005 handed this code to GSD to use as the foundation for building a hybrid isentropic coordinate global model.

Over the next few years, such a model, called FIM, was built, and based on the original design of the horizontal (Arakawa "A" grid and differencing by MacDonald and Lee, but using an "Arbitrary Lagrangian-Eulerian" (ALE) framework for the vertical coordinate developed by Dr. Rainer Bleck for the well-regarded Hybrid Coordinate Ocean Model (HYCOM). The ALE framework for the hybrid-isentropic vertical coordinate is FIM's most distinctive feature, having the advantage of accuracy by reducing transport to a quasi-two-dimensional problem over most of the domain, excepting areas where diabatic effects are dominant. By adapting the physics then being used in NCEP's Global Forecast System (GFS), the FIM began producing real-time forecasts based on initial conditions from the GFS in 2009. Since then, the FIM has been substantially upgraded both in its numerical procedures and in its use of the latest operational version of the GFS physics suite. Moreover, an icosahedral version of the ocean model HYCOM (called i-HYCOM) has been constructed and coupled to FIM.

Research to Applications: The FIM's anomaly correlation scores for 500mb height have rivaled and slightly exceeded those of the GFS since 2012, demonstrating the viability of both the hybrid isentropic coordinate and the numerical procedures used on the icosahedral grid. FIM has participated in the Hurricane Forecast Improvement Project since 2011, producing tropical cyclone track forecasts competitive with the GFS and even the ECMWF. It also participates as one of the high-resolution global hydrostatic models producing twice daily 15km-grid-spacing forecasts for the Sandy-Supplemental-funded High Impact Weather Prediction Project (HIWPP). At a yet-to-be-determined date, the coupled FIM-iHYCOM is a candidate member of the sub-seasonal North American Multi-Model Ensemble (NMME). The NMME aims to improve operational forecast skill on intraseasonal to interannual time scales and to provide real-time forecasts to user communities.

3. Non-hydrostatic Icosahedral Model (NIM)

Research Description: ESRL/GSD began development of a 3-km, non-hydrostatic, cloud-resolving version icosahedral model, related to FIM, in 2010. The goal is to improve numerical accuracy for weather and climate simulations at ultra-high resolutions, as well as to utilize leading edge high performance computing architecture such as Massively Parallel Fine-Grain (MPFG) to optimize model runs for timely forecasts.

Research to Applications: In July 2015, based on the results from HIWPP testing and evaluation of model dynamical cores, NIM was not selected by NWS as one of its next-generation, non-hydrostatic models primarily because it wasn't as mature as the two selected models. Given that decision, GSD has significantly reduced its investment in NIM development, but will continue to use it as an experimental model with which new science and techniques can be tested first before being nominated for infusion into NOAA's current operational global model.

4. Developmental Testbed Center (DTC)

Research Description: Sponsored by NOAA, the U.S. Air Force, NCAR, and National Science Foundation, the multi-agency Developmental Testbed Center facilitates and conducts major tests and evaluations of improvements to NWP forecast system components provided by the NWP research community. It should be noted that the scope of the DTC has recently been expanded to involve global, as well as regional, NWP. These tests and evaluations are critical for selecting proposed changes that need to be transitioned to operational centers. For example, DTC evaluations will be 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 Rapid Refresh (RAP) model, and by the Next-Generation Global Prediction System (NGGPS). GSD DTC staff also conduct tutorials for the modeling community on the HWRF model, GSI/EnKF data assimilation system, and other operational codes.

Research to Applications: Over the past five years, the DTC has put in place several mechanisms to facilitate the use of operational models by the general NWP community, mostly by supporting operational codes and organizing workshops and tutorials. Some of those are: the GSI Workshops in 2013, 2014, and 2015; the 2014 HWRF tutorials in College Park, MD and Taiwan; and the 2015 tutorial on the Non-Hydrostatic Multiscale Mesoscale model in the B-grid (NMMB). This year the DTC completed a project, NWP Information Technology Environment (NITE), which focuses on infrastructure design elements that can be used to facilitate a closer collaboration between the research and operational groups and improve transition of research products to operations. Finally, over the last few years DTC has conducted several tests that led to the transition of innovations to NCEP. Some examples for HWRF are improvement of surface fluxes and of cloud-radiation interactions for the 2014 and 2015 operational versions of HWRF, respectively.

Observing System Experiments (OSE) and Simulations (OSSE)

OSSEs are needed for an objective evaluation and to optimize the utilization of existing data. They are an extension of OSEs, which use data denial experiments to determine the impact of existing observing systems. Atmospheric OSSEs determine the impact of new systems by performing data denial experiments that assimilate “synthetic” observations simulated from a realistic *nature run* stipulated to represent the “true” atmosphere. For the OSSEs to produce accurate quantitative

results, all of the components of the OSSE system must be realistic. This includes (1) a nature run that represents the main characteristics of the real atmosphere, (2) realistic differences between the nature run model and the model used for assimilation and forecasting should exist, (3) existing and new proposed observations should be simulated with realistic coverage and accuracy, and (4) the entire OSSE system must be validated to ensure that the accuracy of analyses and forecasts, and the impact of existing observing systems in the OSSE environment are comparable to the accuracies and impacts of the same observing systems in the real world.

Designing optimal configurations for observing systems is a new growth area within GSD, and it complements GSD's long history in designing instrumentation. This is one of the main reasons why GSD's Global Observing Systems Analysis (GOSA) Group was established. Furthermore, GSD is an active member of NOAA's Quantitative Observing System Assessment Program (QOSAP), which coordinates and prioritizes OSEs and OSSEs within NOAA's Line Offices, and participates in NOAA OSSE Testbed activities.

1. Unmanned Aircraft System OSEs/OSSEs

Research Description: GSD collaborated with many different institutions to develop an OSSE framework and implement it at ESRL in support of the NOAA Unmanned Aircraft Systems (UAS) Program. GSD is a key participant of the Sensing Hazards with Operational Unmanned Technology (SHOUT) project by performing OSEs and OSSEs to evaluate the impact of current and future instruments on the Global Hawk in terms of global forecast skill, to help select instruments for future flight campaigns, and to design optimal flight patterns. Within this project, GSD's focus is on high-impact weather events in mid-latitudes. GSD has also supported flight campaigns by providing input on potential developing storms and finding areas of larger sensitivity to error growth with the use of targeted observation techniques.

Research to Applications: Observations from the Global Hawk's FY15 flight campaign were operationally assimilated into the NWS National Hurricane Center. GSD has developed a methodology to support real flight campaigns and to evaluate the impact of future observations. Results of this work will be published in a peer-reviewed journal and presented at different conferences.

2. Global Navigation Satellite Systems (GNSS) Radio Occultation (RO) OSEs/OSSEs

Research Description: NWS/NCEP has successfully assimilated RO observations into its Global Data Assimilation System since May 2007. Since then, GSD has continued to develop new algorithms to improve the utilization of these observations in NOAA's operational models. GSD has a large expertise on the GNSS-RO technology and GOSA's Chief is the Program Scientist for the COSMIC-2 mission (a US-Taiwan GNSS-RO mission). GSD has established a 5-year 3-way MOU with NESDIS and NWS to maintain R2O work and to support the COSMIC-2 mission. Finally, and in collaboration with JCSDA and AOML, GSD is conducting studies to quantify the impacts of additional GNSS-RO data on operational forecast models.

Research to Applications: Improved GNSS-RO assimilation algorithms were transferred to NCEP and became part of their upgraded operational forecast system. Initial results with a preliminary OSSE

configuration demonstrated that overall increasing the number of RO satellites for data assimilation from 6 to 18 improves weather forecast skill: 18 satellites is better than 12 satellites and 12 satellites is better than 6 satellites. Experiments are now being repeated with a more state-of-the art OSSE configuration and results will be reported to U.S. Congress by the end of 2015. Results will also be published in a peer-reviewed journal.

3. Observation Sensitivity Experiments

Research Description: Observation sensitivity experiments are designed to assess the relative contribution to forecast accuracy of various observation systems. This may be for the purpose of evaluating well-established observation types, such as rawinsondes and surface observations, relative to newer observations such as satellite radiances or satellite-derived atmospheric-motion vectors. It may also be for purposes of evaluating a new observation type, such as GPS-Meteorology, to see if its use contributes to forecast improvement, given the mix of existing observations. To conduct these experiments requires access to a complete set of data that is being used at the operational centers as well as access to any experimental data that are to be assessed. In addition, a state-of-the-art data-assimilation/forecast system, including the forward models needed to effectively use experimental data, must be used. Preferably, this will be an operational system in order for results to be more directly relevant to operations.

Typically, such experiments are first conducted by running the assimilation / forecast system for a certain retrospective period with the total suite of observations. Normally this control run would give the most accurate forecasts. Next, successive experiments are conducted by removing one observation type at a time (keeping all the others) and measuring the extent of degradation relative to the control. These runs indicate the contribution of each omitted observation type. Results from well-conceived and -designed observation sensitivity experiments, together with the relative costs associated with each data platform, can in principle form a rational basis for prioritizing the importance of each platform in relation to its cost.

With its own data-assimilation/forecast system, GSD has always been aggressive in obtaining and using new observation types in order to evaluate their actual or potential contribution to operational forecasting. Motivated by its leadership in rapidly updating, short range NWP, GSD has performed a number of studies of new instrumentation types, including radar wind profilers, GPS-Met and aircraft, in conjunction with development of, first, the RUC model, then the RAP and HRRR models.

Research to Applications: The observation sensitivity experiments have been directed toward application to short-range forecasts over the CONUS, such as: an exhaustive study using the Rapid Update Cycle; an early assessment of observation impacts in the RAP model presented at the WMO Observation Impact Workshop in 2012 at Sedona, AZ; an assessment of aircraft observations using RAP for the NOAA Aircraft Data Workshop in 2014; and a more comprehensive experiment including satellite radiance assimilation earlier in 2015, for which a manuscript is in preparation. The latter showed that aircraft observations were the most important observation type, the first time that radiosondes were relegated to second place in the regional experiments that GSD has conducted. An observation sensitivity experiment is currently underway to examine the impact on

forecasts of convection in the HRRR from assimilation of GOES super-rapid-scan atmospheric motion vectors.

4. Satellite Product Assessments: Global Precipitation Measurement (GPM) and Atmospheric Motion Vectors (AMV) Cloud Drift Wind Data for GOES-R Preparation

Research Description: Beginning in October 2013, GSD started collaborating with the Joint Center for Satellite Data Assimilation (JCSDA) and NASA to evaluate the utility of PMM (GPM + TRMM) space-based radar data for initializing a weather forecasting model. Case studies running with and without TRMM radar data along with ground based radar are being performed. The GPM satellite system consists of a core satellite and a constellation of additional satellites. The use of space-based radar in combination with microwave sensors will also be considered in design recommendations for operational assimilation systems. The space-based radar can be used to help calibrate and leverage the more abundant microwave sensors to provide the most complete picture of global hydrometeors for use in models.

Beginning in January 2014, GSD started collaborating with the National Severe Storms Laboratory (NSSL), NESDIS and CIRA to evaluate the utility of satellite AMV cloud drift wind data, merged with other commonly available observations for initializing a weather forecast model. GOES (SRSOR) Rapid Scan satellite data are being used to help prepare for GOES-R. A number of modeling case studies are being performed to compare analysis and forecast results both with and without the AMV data. Comparison of cloud analysis hydrometeor fields with rapid scan satellite imagery data is an ancillary benefit of this collaboration with NSSL.

Research to Applications: The GPM assessment results and report will be presented in December 2015 at the American Geophysical Union meeting, and in a document provided to NESDIS. The assessment results for GOES-R preparation will be reported via NSSL on a regular basis through September 2016.

GSD. For more information on MADIS, refer to https://madis.noaa.gov/.

5. GPS-Meteorology (Ground-based)

Research Description: Global Positioning System meteorology (GPS-Met) system was developed by GSD to offer high temporal resolution, all-weather observations of precipitable water (PW) with accuracies comparable to radiosondes and surface microwave radiometers. These observations are assimilated into operational models and are used to validate in situ, satellite and model PW estimates. Since 2010, GSD has worked with private companies, other government agencies, other NOAA organizations, and universities to 1) use GPS-Met data to validate offshore weather predictions and investigate the accuracy of polar orbiting satellite vapor estimates; 2) demonstrate that "blackbox" zenith tropospheric delay (ZTD) estimates from commercial GPS data vendors should be verified to insure their accuracy is suitable for meteorological applications; 3) assisted with GPS-derived water vapor estimates to study deep convective time scales in the Amazon, and 4) assisted in verification of a new GOES precipitable water vapor retrieval algorithm which improved the accuracy and utility of GOES PW observations. GPS-Met data is assimilated in both NWS

operational and OAR experimental weather forecast models and is used by forecasters to improve situational awareness. For more information, please visit http://www.gpsmet.noaa.gov/.

Research to Applications: In FY2014, a CRADA was awarded to Trimble, Ltd. The CRADA with Trimble demonstrated that commercial vendors can meet NWS requirements for atmospheric water vapor data used in operational models and for nowcasting. NWS was able to obtain the GPS-Met data through the one-year Mesonet Data Buy contract and will perform an initial assessment of the quality of the data in Q1 of FY16. At the same time, NWS will begin a more robust, fully competed, multi-year procurement process in first quarter of FY16 to purchase only the GPS-Meteorology data that will have more detailed requirements and quality thresholds. GSD will work closely with NWS during this process to ensure data quality and continued data delivery to NWS operational MADIS.

Renewable Energy

Research Description: ESRL's efforts to assist with renewable energy sector began in 2008 and accelerated with a Department of Energy/National Renewable Energy Laboratory collaboration that began in 2010. In FY2013, Congress provided funding to ESRL for continued development of model physics and data assimilation to improve wind and solar prediction. The main focus of the ERSL Renewable Energy Program is to improve the skill of the 13-km Rapid Refresh (RAP) and 3-km High Resolution Rapid Refresh (HRRR) weather models, which the renewable industry considers state-of-the-art. Our efforts focus on improvements in skill of forecasting wind-turbine-height-winds and surface solar irradiance, which greatly impact the amount of wind and solar power, respectively, which can be produced. In the Wind Forecast Improvement Project-1 (WFIP1), GSD improved boundary-layer parameterizations in the RAP and HRRR using the modified Mellor-Yamada-Nakanishi-Nino (MYNN) scheme, such that the diffusion of momentum and heat more accurately simulate the low-level jet. These modifications to the surface-layer mixing length formulation have reduced the (high) bias in the forecasts of 10-m and 60-m wind speeds during the daytime. Also from WFIP1, GSD improved the surface-layer parameterization using the modified MYNN scheme, such that we reduced the (high) bias in the sensible heat fluxes in the previous version of the scheme. This reduction in sensible heat flux bias allows us to make more accurate forecasts of temperatures at 2m above ground. Lastly, in the WFIP1, GSD improved the RUC Land Surface Model (RUC LSM), utilized in the RAP and HRRR, by increasing the aerodynamic roughness lengths, further reducing the high 10-m wind speed bias. Additional layers were added to the RUC LSM soil model, allowing for a more accurate characterization of the heat conduction within the soil and an improved diurnal variation of the surface temperature. Together, these modifications allow the RUC LSM to more realistically represent the exchanges of heat, moisture, and momentum with the overlying atmosphere, which is crucial for low-level wind forecasting.

For the upcoming Wind Forecast Improvement Project-2 (WFIP2), the 13-km RAP, 3-km HRRR, and a 750-m HRRR Nest over the Pacific Northwest will be improved to better model turbine-height winds in regions of complex terrain. Specifically, in the PBL scheme, GSD will work to make parameterizations fully "scale aware", including the development of 3D turbulence parameterization. Additional research will pursue z-less mixing-length formulations, the development of an eddy-diffusivity / mass-flux capability within the MYNN, and improved subgrid-scale cloud parameterizations. For improved surface-layer modeling, GSD will pursue sub 3-km

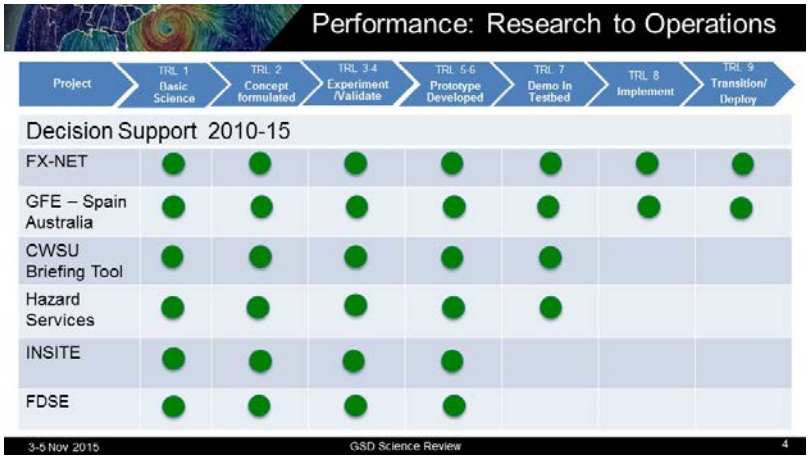
grid spacing within complex terrain. For the forest canopy model GSD will strive for very high vertical resolution ($dz < 10$ m), and not resort to surface-roughness modifications to parameterize tall canopies. For the land-surface model, GSD will focus on heat and moisture fluxes with an aim to improve the lower-boundary condition for PBL. To improve subgrid-scale cloud representation (especially unresolved stratiform clouds), GSD will aim to develop a prognostic statistical cloud scheme with full radiative coupling. And for shallow cumulus parameterization, GSD will seek development of a scale-aware prognostic scheme with appropriate closures and stochastic capability.

Early 2015 in the Solar Forecast Improvement Project (SFIP), values for Global Horizontal Irradiance (GHI) were provided for the first time ever in the RAPvX model. In September 2015, GSD provided output for Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI) in the ESRL HRRR-X model. For further information, visit http://www.esrl.noaa.gov/research/renewable_energy/

Research to Applications: The WFIP1 improvements were in RAPv2 that went to NCEP in 2014. The SFIP improvements including the first-ever GHI output in ESRL RAP-X and the DNI and DHI in the ESRL HRRR-X will be implemented in the operational RAPv3 and HRRRv2 with the next NCEP implementation (scheduled for February 2016). Improvements from WFIP2 will be incorporated into RAP and HRRR and transitioned to NCEP in 2018 and 2019.

Decision Support

Research to Operations/Applications – Transition Readiness Level



Key:
GFE – Graphical Forecast Editor
CWSU – Center Weather Service Unit
INSITE – INtegrated Support for Impacted air-Traffic Environments
FDSE – Forecast Decision Support Environments

Decision Support Systems

A Weather-Ready Nation requires system and software tools to help decision-makers issue and communicate timely and accurate weather information, including potential impacts from weather events. GSD works with decision-makers to understand their needs and develop decision support tools responsive to those needs.

1. Advanced Weather Interactive Processing System (AWIPS) Enterprise

Research Description: AWIPS, the information system used nationwide by the National Weather Service (NWS) for forecast operations, is the result of exploratory development and technology transfer conducted by GSD and its predecessor, the Forecast Systems Laboratory, since 1979. The first deployment of AWIPS to NWS Weather Forecast Offices (WFOs) was in 1998 followed by multiple enhanced operational builds by GSD through January 2010.

AWIPS has undergone a significant transition over the past ten years to a contractor-built (Raytheon), Java-based, service-oriented architecture now called AWIPS-II. However, by design, the look-and-feel of AWIPS-II is nearly identical to AWIPS-I and runs on the same hardware platform in the WFO's. This transition was completed by the end of FY15 and NWS will award a new 10-year contract for its maintenance and evolution in 2016.

Research to Applications: In the past five years, GSD has continued to be involved in the original AWIPS maintenance and enhancements which transitioned to NWS AWIPS during the AWIPS-II development and installation period. GSD also helped with the development and evaluation of AWIPS-II during its field evaluation and deployment phase. Specific AWIPS-II developments such as Forecaster Decision Support Environment (FDSE) and Hazard Services are discussed in the following sections.

2. Graphical Forecast Editor (GFE)

Research Description: The Graphical Forecast Editor (GFE) further NWS forecasting operations using AWIPS. Developed by GSD beginning in the early 1990s, the GFE is used by field staff (initionally at Weather Forecast Offices and now moving into River Forecast Centers and the NWS/NCEP National Centers) to prepare a gridded database of weather elements extending out to seven days. This database is used to automatically generate routine forecast products (e.g., zone forecasts, point-and-click Web forecasts) and is also the basis for issuing and tracking long-term hazard statements and warnings (e.g., winter storms, wind storms).

Much of the development work over the past five years has focused on the standardization of commonly-used smart tools and procedures for NWS operations. This allows for easier maintenance and upgrades of these tools, as needed. GSD leads this activity through the NWS GFE Migration Strategy Group (GMSG). Development has also been done for improved aviation impact variables (e.g. ceiling and visibility, turbulence, and icing), and automated text generation for Terminal Aerodrome Forecasts (TAFs) and Tropical Storm text products. For additional information, visit http://www.nwstc.noaa.gov/GFE/GFEBasicUser/.

Research to Applications: The GFE suite of software has been adopted by private industry and the meteorological services of other nations, such as The Central Weather Bureau (CWB) of Taiwan, and by the Bureau of Meteorology in Australia in 2006-2011 and the Spanish Meteorological Agency in 2010-2014. Beginning mid-2012, an additional focus has been on the expanded use of GFE at the NWS/NCEP National Centers and collaboration on forecast grids between the Tropical Prediction Center and coastal WFOs.

3. Hazard Services

Research Description: NWS hazard operations needed to be simplified and streamlined to provide forecasters better tools to perform their mission-critical job of providing lifesaving watches, warnings, and advisories. GSD collaborated with NWS and Raytheon Technical Services to combine functionality from three AWIPS-I legacy warning applications into an application for AWIPS-II. For more information, please visit: http://integratedhazards.noaa.gov/

Research to Applications: The December 2015 field release of AWIPS-II will include a version of Hazard Services that will allow forecasters across the nation to experiment with the new functionality for hydrological hazards in a "Practice mode" setting. Input from the forecasters will be incorporated into the software to produce an operational system. The new functionality also supports disseminating hazard information through social media and mobile devices, and two-way

exchanges between NWS forecasters and external partners such as emergency managers and law enforcement agents.

4. Forecaster Decision Support Environment (FDSE)

Research Description: The FDSE project (led by NWS) is a collection of risk reduction activities designed to test ideas and operational concepts for the forecast office of the future. FDSE will identify, develop, and test Environmental Intelligence Management Capabilities designed to enable the Weather Forecast Office forecasters to exploit the full range of data, tools, and knowledge available in the 2018 timeframe. The FDSE will not replace existing data processing and distribution mechanisms (e.g., AWIPS II and broadcast by the SBN) but rather will use these mechanisms as a strong foundation that will then be refined and augmented to deliver the enhanced capabilities as defined in the NWS Roadmap. A primary goal is to allow forecasters more time to devote to Impact-based Decision Support (IDS) within their areas of responsibility. Capabilities developed within the FDSE context will be implemented whenever they are determined to be operationally viable and can be transitioned to operations.

Four specific areas of development have been identified for initial GSD-lead development:

- Hydrometeorological Grid Monitoring - Provide real-time grid monitoring tools to identify deviations between forecast and observed sensible weather elements to prompt forecaster intervention in the process. Additional monitoring of significant impact weather events and climatological anomalies will be added this year for evaluation.

- Short-term Forecast Update Tools - Develop a new generation of smart initializations and model consensus approaches to streamline the forecast database population process and automate current labor-intensive processes.

- Short-term Forecast Point Blend Method – Develop a model weighting scheme that is based on a comparison between an objective analysis and the recent performance of each model for any given forecast point in the office's area of responsibility.

- Model Ensembles - Provide intelligent verification-based statistics and the capability to select different model ensemble options rather than direct grid editing. The software will be available for WFO testing and evaluation via an AWIPS Test Authorization Note (ATAN).

Research to Applications: Over the past two years (2013-2014), initial prototypes for these four capabilities were developed and refined, based on user feedback. The focus for 2015-2018 is "operationalizing" these initial capabilities, hosting a workshop, and testing in NWS Operational Proving Ground to determine the best methods and operational procedures for these FDSE components. For example, work is near completion on the initial ensemble tool integration into the December 2015 field release of AWIPS-II to allow testing by and feedback from forecasters.

5. AWIPS-Based System Support for Fire Weather: FX-Net System

Research Description: FX-Net began as a prototype meteorological PC workstation providing access to the basic display capability of an AWIPS I workstation via the Internet. The FX-Net system provides full AWIPS visualization and data analysis capability with a Graphical User Interface (GUI) that closely emulates the standard AWIPS I workstation, allowing the NWS Incident Meteorologists (IMETs) to move seamlessly between their Weather Forecast to FX-Net in the field. In 2001, FX-Net was integrated into NWS operations through its regional offices with continued support from GSD.

As FX-Net has evolved, new products have emerged such as Gridded FX-Net which is also used by field-offices for retrieving and manipulating model data. Gridded FX-Net is an AWIPS I workstation architected by GSD to work from a network-remote location. For further information, visit http://fx-net.noaa.gov/.

FX-Net and Gridded FX-Net are actively being used by the National Interagency Fire Center (U.S. Forest Service, Bureau of Land Management, and others) in support of their Geographic Area Coordination Centers (GACCs) during fire weather season. This operational use allows GSD to develop and evaluate next generation system designs such as client and server virtualizations (referred to as FX-CAVE) which can feed back into the NWS AWIPS-II evolution.

Research to Applications: The FX-Net support for IMETs and aviation was fully transitioned over to NWS ownership in FY2013.

6. AWIPS-II-Based System Support for Fire Weather: FX-CAVE System

Research Description: The FX-CAVE workstation is the next generation of meteorological workstation based on the AWIPS II CAVE workstation. It will eventually make the FX-Net System obsolete. The National Interagency Fire Center (NIFC), and its eleven field offices, are transitioning to FX-CAVE starting in 2015. Agreements are in place to proceed indefinitely with this interagency cooperation. Like FX-Net, FX-CAVE is another successful experimental application of the GSD blueprint which remains unchanged for 30 years: work with users to determine requirements, build solution systems, and iterate.

Research to Application: In addition to the FX-Net workstation, the GACC forecasters are beginning to use FX-CAVE: Two remote Virtual Machine users (Boise and Albuquerque) and two desktop application users (Redding and Boise) will provide feedback to GSD developers. The GACC forecaster in Albuquerque used (and continues to use) a virtual FX-CAVE application served entirely from GSD for almost the entire 2015 fire weather season. Not only was the forecaster provided with excellent performance and reliability from FX-CAVE, but a working model of a future enhancement to AWIPS-II was demonstrated convincingly.

7. Hurricane Forecast Improvement Program (HFIP): Consolidated Display of Products

Research Description: After Hurricane Katrina, Congress provided significant research funding to several organizations for better hurricane prediction. NOAA's HFIP program provided funds to GSD to develop a website which consolidates and centralizes the products from different experimental

and operational weather and hurricane models and effectively displays them in uniform formats for comparison. For more information, see http://www.hfip.org/products/.

Research to Applications: Starting in 2012, the website displaying the various HFIP products was used by National Hurricane Center (NHC) forecasters, NWS managers, and FEMA managers who continue to use the information provided as a quasi-operational forecasting tool for tropical weather events. NHC said that the "website is great and most impressed with the fact that it works on their iPads and smartphones".

8. INtegrated Support for Impacted air-Traffic Environments (INSITE)

Research Description: INSITE is a web-based prototype that extends the typical use of forecast weather information by combining it with air traffic data to determine potential impacts to aviation operations. INSITE incorporates weather information from observations as well as from five convective weather forecast products. In addition to displaying the original weather products, a constraint field derived from each forecast product using a combination of weather and traffic density information is provided, highlighting potential impacts to air traffic based upon the forecast weather. INSITE also provides a weighted average of the five constraint forecasts, considered a 'synthesis' of the products. Each constraint forecast includes a measure of confidence of that forecast, or in the case of the synthesis, a measure of the consistency between the five member forecasts. Another key feature of INSITE is that the user can interact with the application to outline a region of interest to determine the severity of constraint within that region. More detailed constraint information can be viewed specific to this region with respect to airways or Air Route Traffic Control Centers (ARTCCs) that intersect it.

Users of INSITE include AWC forecasters, the National Aviation Meteorologist at the FAA Air Traffic Control Systems Command Center, and local WFO and Center Weather Service Unit (CWSU) offices. For further information, visit http://esrl.noaa.gov/fiqas/tech/impact/insite/

Research to Applications: Work is ongoing to transition INSITE to NWS operations in the May-June 2017 timeframe.

Assessment and Verification

GSD performs in depth assessments of forecast quality to verify that the most accurate weather information is provided to planners and decision makers, including assessments of new software products' readiness for NWS operations. This work is supported by both the FAA and NWS.

1. Technical Reports for NWS and FAA/AWRP

Research Description: To provide targeted weather information to aviation weather consumers, the Federal Aviation Administration Aviation Weather Research Program (AWRP) is developing automated aviation weather forecast products for icing, turbulence, ceiling and visibility, and convective weather. Prior to the transition of these products to NWS operations, these forecast products are extensively evaluated for quality and accuracy. GSD provides this independent assessment as the Quality Assessment Product Development Team and is responsible for delivering

scientific evidence of product quality in the context of aviation operations. The customers of AWRP weather products include the aviation industry, FAA operations, and NWS Aviation Weather Forecasters. The customers of the GSD evaluations include: the FAA AWRP as part of their research transition process, aviation weather product developers, and FAA Project Managers and decision makers.

Research to Applications: Over the past 10 years, GSD has evaluated 19 weather products for transition to NWS operations. Of those products, eight have completed a full transition to operations. The related GSD publications can be found at the following web site: http://esrl.noaa.gov/fiqas/publications.html

2. TRACON Gate Forecast and Verification Tool

Research Description: Certain CWSU offices produce a TRACON (Terminal Radar Approach Control) Approach and Departure Gate Forecast product communicating potential convection-based impacts to sectors within the TRACON using a traffic light format. The NWS Aviation Weather Center has developed an automated tool to centralize production of these forecasts, and in the future will allow forecaster-over-the-loop edits to the automated product. The NWS Aviation and Space Weather Services Branch has tasked GSD to develop a peer automated verification tool that will produce performance metrics of the automated and forecaster-modified products, with statistics made available via a web user interface.

Research to Applications: GSD has developed a prototype tool that provides performance metrics for the automated output, including both traditional techniques and event-based techniques that measure skill with respect to the onset and cessation of impactful convective events. Activities in 2015-16 include expansion of the tool to incorporate forecaster-modified output, and preparatory activities for transition of the tool to NWS operations in 2018. This tool will be used to track performance for the automated forecast product as well as the value added by the human forecaster.

3. CWSU Briefing and Verification Tool (CBVT)

Research Description: NWS meteorologists at the 21 Center Weather Service Units (CWSUs) provide decision support services at FAA Air Route Traffic Controller Centers (ARTCCs). The CWSU meteorologists provide routine and on-demand briefings containing weather forecast information critical to FAA Traffic Flow Management (TFM) decisions (e.g., winds that could affect runway configuration changes, ceiling and visibility). Each CWSU is required to track and verify their forecast information for specific variables, which is currently done manually, with approaches that vary by CWSU. As part of the NWS initiative to centralize and standardize verification processes that are currently performed manually by individual CWSUs, the Aviation and Space Weather Services Branch has funded GSD to develop the CBVT. This tool is a prototype web application allowing CWSU forecasters to enter forecast information they have provided to TFM for wind events impactful to current terminal configurations. The tool will also provide automated verification capabilities for these forecasts and the results will be used by the NWS to track and report performance metrics to the FAA as part of their quality assurance activities.

Research to Applications: The tool is currently being tested and evaluated by a subset of CWSUs established as a focus group, and will be expanded in 2015/16 to provide automated verification capabilities for these forecasts. The tool incorporates event-based verification techniques that measure forecast performance with respect to onset of impactful wind events.

4. Verification Requirements Monitoring Capability (VRMC)

Research Description: VRMC is an automated, web-based application developed by GSD that supports the product assessment and monitoring activities sponsored by the FAA Aviation Weather Research Program. The VRMC serves as a supporting tool for formal, in-depth forecast quality assessments; provides an ongoing historical performance record of forecast quality to serve as a baseline for evaluating future developments in aviation weather products; and provides a platform for assessment and methodology configuration management and statistical baseline control. The tool incorporates verification techniques that measure product quality relative to operational decision criteria, for both Turbulence and Icing products. Verification statistics are computed via backend processing, stored in a relational database, and made available via a web interface in the form of graphical plots and tables.

Research to Applications: The VRMC has Icing and Turbulence components that correspond to formal quality assessments performed by GSD as part of the FAA AWRP-sponsored Quality Assessment Product Development Team. The verification results have been utilized in quality assessment reports as part of the AWRP formal transition process of aviation weather products into operations.

5. Real-Time Verification System (RTVS)

Research Description: The National Weather Service has a need for a comprehensive and adaptive verification/performance management system to collect, report, and interpret key measures and indicators related to the quality, timeliness, accuracy, and usefulness of its products and services. As part of this comprehensive NWS verification system, the NWS has stated the need for an aviation verification capability. The Real-Time Verification System (RTVS) was developed to provide automated verification of aviation weather products and was a technological opportunity for the NWS. RTVS provides automated real-time verification tools for four aviation weather service areas: convection, ceiling and visibility, icing, and turbulence. RTVS is currently the most comprehensive system of ongoing performance metrics for NWS Aviation Weather products, and provides a historical performance record for aviation products that is used to track and improve the quality of aviation forecasts, as well as a feedback mechanism to managers, forecasters, and operational planners. RTVS users include the NWS Aviation and Space Weather Services Branch, NWS Aviation Weather Center, Alaska Aviation Weather Unit, Center Weather Service Units, and others.

Research to Applications: RTVS has been operated by GSD staff since 1999 in a quasi-operational mode to support the historical record of NWS aviation forecast performance, feedback to NWS and Federal Aviation Administration (FAA) aviation forecasters, managers, and decision makers, and the transition of experimental forecast products into NWS operations. Monthly reports of verification statistics from RTVS are provided to the NWS for product performance tracking.

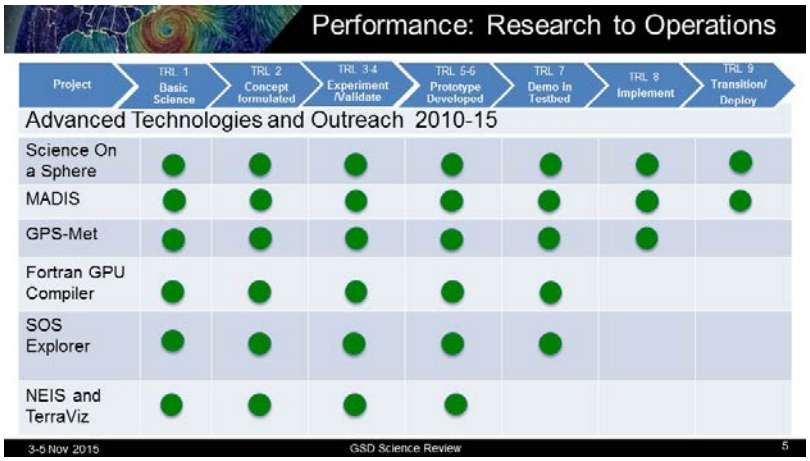
6. Event-Based Verification and Evaluation of NWS Gridded Products Tool (EVENT)

Research Description: The EVENT Tool, sponsored by NWS Aviation and Space Weather Services Branch, supports NWS efforts to measure forecast accuracy relative to aviation traffic flow management decisions. The tool provides ongoing, automated computation of verification statistics that are made available via an interactive web user interface, for users to query results for specific date ranges, issues, leads, or locations. The performance metrics included in the tool are framed by requirements established by the Traffic Flow Management Weather Requirements Working Group, a joint FAA/NWS working group formed to baseline current weather support to Traffic Flow Management and determine requirements for weather services. The underlying verification techniques in the tool are event-based verification techniques that measure product performance with respect to prediction of the onset and cessation of weather events impactful to aviation operations. Current capabilities provide performance metrics for products in the context of thunderstorm events relevant to both terminal and en-route operations, and provide multiple views within the web application to evaluate product performance for several NWS products, including National Digital Forecast Database (NDFD), RAP, Localized Aviation MOS Program (LAMP) product, and HRRR.

Research to Applications: The EVENT tool is an actualization of the NWS and FAA initiative to evaluate product performance in the context of the product's operational use. Beginning in 2011 the tool is used by the NWS to monitor product performance with respect to these new, operationally-relevant performance requirements. It is currently being expanded to incorporate verification capabilities for products with respect to wind events at the terminal and should transition to operations in 2018.

Advanced Technologies

Research to Operations/Applications – Transition Readiness Level



Key:
SOS– Science on a Sphere
MADIS – Meteorological Assimilation Data Ingest System
GPS-Met – Global Positioning System for Meteorology
NEIS – NOAA Environmental Information System
TerraViz – NEIS visualization system
GPU – Graphical Processing Units

Fine Grained Computing Technologies

GSD's High Performance Computing Section supports the development of new models and conducts research and development in next-generation high-end computing. Tools are developed to improve the ability to port, test and run models in diverse computing environments including shared memory clusters, distributed memory Linux clusters, Graphics Processing Units (GPUs), and Many Integrated Core (MIC) fine-grain parallel computers. Modeling support activities include parallelization and optimization of regional and global atmospheric weather models, with occasional focus on upper atmosphere, chemistry and ocean models.

1. Dependency Driven Test System (DDTS)

Research Description: GSD has designed and developed a tool called the Dependency Driven Test System (DDTS) to rigorously compose and test models being modified by scientists, parallelization experts and support staff. A series of regression tests can be composed by scientists, software engineers, or parallel programmers to ensure changes made to source code do not result in unexpected or erroneous results being generated. In addition, computational tests can test the model's ability to run on CPU, GPU, and MIC chips using Message Passing Interface (MPI), OpenMP

and OpenACC compilers to insure correct results and track performance. New tests can be easily composed and added when needed to cover a new model capability or computing requirement. As a result, DDTS is now an essential part of the model development and test cycle at GSD.

Research to Application: Past research and development activities for fine-grain computing includes porting and running a new weather model, called the Non-hydrostatic Icosahedral Model (NIM), on GPUs in 2009, and Intel MIC in 2012 when it became available. NIM code is written in Fortran, with industry standard OpenACC and OpenMP directives used for parallelization that target CPU, GPU, and MIC architectures. The Scalable Modeling System (SMS) is used to support MPI-based parallelization via a support library and directives that are inserted into the code. Collectively, the directives and library allow a single NIM source code to be maintained that has demonstrated good performance and scaling to thousands of CPU, GPU, or MIC devices.

2. Massively Parallel Fine Grain (MPFG) Computing/Compiler

Research Description: In support of Graphical Processor Unit (GPU) research, GSD has developed a compiler to convert our scientific codes, originally written in Fortran, into CUDA, the language supported on GPUs. The Fortran-to-CUDA compiler, called F2C-ACC, was developed to reduce the time required to run on the GPU. CUDA is based on C programming language with some additional extensions to call GPU routines (kernel codes), move data between the host Central Processing Unit (CPU) and GPU and to manage computations and memory on the GPU. The F2C-ACC compiler was developed from 2009-2012 to support the parallelization of the NIM for NVIDIA GPUs. It has also been used for parallelization of its predecessor model called the Flow-following Finite-volume Icosahedral Model (FIM), and portions of the Weather Research and Forecast Model (WRF).

Development of F2C-ACC began before commercial Fortran GPU compilers were available. It has since become the standard by which commercial compilers are judged, and an effective vehicle to gain important and substantial improvements in the openACC compilers. GSD conducted four evaluations of commercial compilers in 2011, 2012, 2014, and 2015. A comprehensive performance evaluation in 2014 showed the Cray and PGI compilers were running the NIM 1.7 and 2.1 times slower than F2C-ACC. GSD worked with vendors to identify and address performance issues by sharing F2C-ACC, code and expertise. As a result, recent results show PGI (Cray evaluation pending) has closed the substantial performance gap and now offers equivalent performance to F2C-ACC.

Research to Applications: The compiler was released to the community in 2009, and has been used by researchers worldwide. GSD worked with vendors to identify and address their compiler performance issues by sharing F2C-ACC, code and expertise. This development has been noted in many web pages and technical documents released by NVIDIA, Inc., the leading manufacturer of GPUs.

Environmental Information Systems

GSD develops technologies that allow users to visualize and answer questions requiring data from different data sources regardless of format or location. In particular, GSD is exploring better

methodologies to help users exploit "big data" resulting from high resolution global models and the latest environmental satellites and sensors.

1. NOAA Earth Information System (NEIS)

Research Description: NOAA's data dissemination, data management and decision support systems are challenged to adequately handle a new wave of data volume and data requests. In addition to increased volume, there is an increase in the velocity of throughput required for structured, semi-structured, and unstructured data flowing into and out of NOAA. NEIS will make the data discovery, access, analysis, and processing agnostic to the visualization environment and interoperable between systems. This will allow legacy systems to utilize the underlying NEIS information management infrastructure to immediately access a suite of real time information needed for the environmental 'problem of the day' allowing NOAA and its partners to do their mission. Sometimes it's a matter of finding, sometimes processing, sometimes accessing, sometimes visualizing diverse information in the context of today's problem. NEIS works to address all of those needs. A patent is pending for the NEIS technology and capability. For further information, visit http://www.esrl.noaa.gov/neis/

Research to Applications: Through the High Impact Weather Prediction Project (HIWPP), NEIS is providing interested parties (researchers, private companies, and public) research grade near real-time data delivery and visualization allowing them to compare and analyze research models. Through this program, participants for the first time have access to new weather forecast models under development and can provide feedback to the model developers on model performance from many different perspectives around the world. Additionally, the NEIS team has worked with the National Weather Service Integrated Dissemination Program (IDP) team to discuss how NEIS is using new technologies and data delivery concepts and how they could be used for future services within the IDP infrastructure to deliver data in a timelier fashion.

2. TerraViz: Using Gaming Technology

Research Description: GSD is using technology created by the video game industry to drive the next generation of interactive data visualization and analysis. While video game technology may seem a strange choice, it takes advantage of existing off-the-shelf technologies. Additionally, it can run on many platforms: desktops, browsers, and mobile devices. A patent is pending for GSD's invention of TerraViz. Video games are a multi-billion-dollar industry, and represent an ideal choice for providing a wealth of data to a user in realtime. The industry harnesses the power of graphics card technology (GPUs) available in commodity PCs to render and display information in efficient ways. For further information, visit http://www.esrl.noaa.gov/neis/library/terraviz-video.html

Research to Applications: As research progressed it became clear that TerraViz could be used for both scientists and educators. Two different products emerged - the NOAA Earth Information System was developed for scientific use and SOS Explorer™ was developed for educational and public use. SOS Explorer™ creates an interactive Earth for flat screen displays including those projected on walls, computers, and large displays, providing teachers, students, and the public their own personal SOS. In addition, tools included in the application allow users to zoom into, probe,

and graph the data, as well as add supplementary material including websites, videos, pictures, and place marks.

3. Specialized Information and Warning Systems

Research Description: GSD develops prototype systems and tools that explore ways to better communicate the impact of weather events, weather related hazards, and other natural disasters to non-scientist and operational decision makers. The Specialized Information and Warning Systems include the following three different systems:

- The Traffic Management Unit (TMU) project started in 2001 and was an effort to take all the convective hazard products and combine them in a graphic that could be easily understood by FAA Air Route Traffic Controllers to help with their air traffic routing decision making process. TMU efforts experimented with displays tailored for FAA traffic manager's use, improved briefing capabilities, improved methods for integrating data, and tools for forecasters to facilitate the creation, delivery, and accuracy of forecasted impacts to airspace.

- The Volcanic Ash Coordination Tool (VACT) started in 2004 with a goal of improving the ability to coordinate and communicate the impacts of a volcanic ash event. The project explored tools for collaborating, briefing, forecasting, and sharing of data to improve the warnings and watches that were issued for volcanic events.

- The Geo-Targeted Alerting System (GTAS) started in 2009 to improve the understanding of impacts to society of a toxic chemical release. The GTAS system incorporated the latest advancements in chemical plume modeling, high resolution weather models, and network-enabled operations to build upon NWS operational meteorological information and warning infrastructure and the Federal Emergency Management Agency's (FEMA) Integrated Public Alert and Warning System (IPAWS) to enable emergency managers and first responders from their desktops to collaborate with their local Weather Forecast Office to provide more accurate and timely warnings for toxic plume events.

Research to Applications: TMU: AWIPS-II aviation product display capabilities came directly from TMU efforts. TMU and VACT: Provided requirements for AWIPS-II collaboration, thin client, and drawing tools. GTAS: By 2011, GTAS had been implemented in seven cities as well as FEMA headquarters in Washington, D.C. and although GTAS met all the FEMA requirements, FEMA discontinued funding after FY2011 and the project was discontinued.

4. Meteorological Assimilation Data Ingest System (MADIS)

Research Description: MADIS is a global database and delivery system developed at ESRL/GSD beginning in July 2001 that serves the greater meteorological community by supporting the collection, integration, quality control, and distribution of many thousands of NOAA and non-NOAA observations. This includes observations from over 60,000 surface mesonet stations from local, state, and federal agencies, plus private networks. MADIS also collects upper-air data sets, including multiagency wind profilers, and ground-based radiometer observations.

The purpose of MADIS was to leverage the many public and private observations available by integrating them into a single database in a form that could easily be used by data assimilation, numerical weather prediction models, and forecasters. MADIS receives these observations with different formats, units, and time stamps, and integrates them into a single uniform database. The wealth of observations available through MADIS improves the lead-time of forecasts and severe weather warnings. In addition to providing the assimilated data in near real time, MADIS also supplies data providers with quality control and station monitoring information to assist in their maintenance activities and to enhance and promote the mutual benefits of public/private data sharing.

Research to Applications: MADIS achieved quasi-operational status at NWS on September 30, 2010. The transition to full operations at NWS was completed January 21, 2015. Three systems were transitioned into operations: a real-time system for ingest, processing and distribution; a data recovery system; and an archival system. Operational MADIS is administered and supported by NCEP Central Operations (NCO) with the MADIS archive being housed at the NESDIS National Centers for Environmental Information (NCEI) and improvements to the system being provided by

Science On a Sphere® (SOS) Program

1. SOS Technology, Data, and Installations

Research Description: Technical innovation and development of the SOS system's capabilities has rapidly progressed since 2010, with regular software releases and new technology deployment made at SOS sites worldwide. Below are examples from three main research areas with status of five years ago versus the current status.

SOS has leveraged available technology improvements in computer systems, projectors, graphics cards, networked cameras, and controller devices.

Hardware for SOS

	2010 Status	2015 Status
Carbon fiber sphere	68" diameter only	68" + smaller/larger sizes
Computer Systems	5 PCs/graphics cards	1 PC/graphics card
Projectors	Standard definition	High Definition & 4K/Ultra HD
Controllers	Wii game controller	iPad/iPhone App (Wi-Fi & Bluetooth)
Alignment	Manual via Wii remote	Visual iPad/iPhone App controls; Automated using computer vision

SOS custom software has steadily improved to provide better preparation and delivery of SOS shows, including SphereCasting to conduct remote broadcasting to other SOS sites, and new widely requested public kiosk software.

Software for SOS

	2010 Status	2015 Status
Visualization	Basic 3D rendering	Added sphere section replication
Giving Presentations	Desktop interface or Wii controller	Full iPad App with data descriptions & customizable presenter notes
Display Tools	Minimal	Annotations, custom cursors, drawing, & regional magnification
Creating Presentations	Text editor for playlists	Graphical playlist editor; Playlist builders on iPad and website
Public Kiosk	Unsupported, 3rd party	NOAA kiosk with easy configuration
SphereCasting	Basic functionality	Full SOS support with streaming video

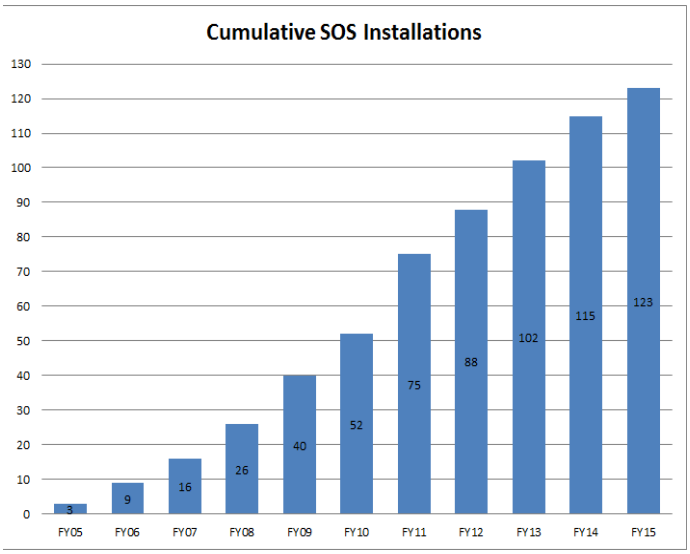
Innovation in hardware and software has enabled greater volumes and resolutions of datasets for SOS. As the data collection has grown, more data management capabilities have been added to the software and website, including localization to support a rapidly growing non-English speaking audience.

Content for SOS

	2010 Status	2015 Status
Real-Time Data	Initial capabilities	0.5 TB of satellite and NOAA model data distributed daily worldwide
Dataset Resolution	Limited to 4K	Datasets with resolutions up to 16K
Data Catalog	File system navigation for a few hundred datasets	Added metadata query and browse for 500+ datasets on website and iPad
SOS Website	Static pages viewed on desktop browsers	Extensive information and dataset access, adaptive to many screen sizes
Language Localization	English only	Chinese website content; Translation support in user interfaces
Use of Data Standards	Common image and movie formats	Display Google Earth KML/KMZ files; Direct web mapping (WMS) support

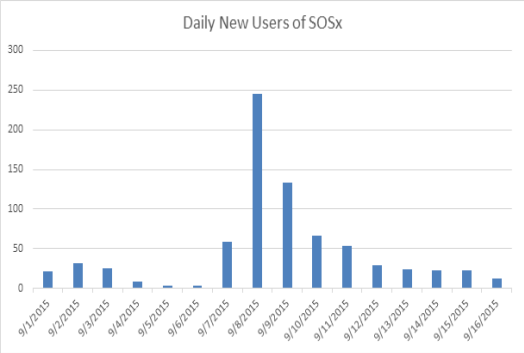
Research to Applications: In June of 2010 the 50th Science On a Sphere was installed. In September of 2015, the 128rd Science On a Sphere was installed. The growth seen by the Science On a Sphere (SOS) project is evidence of the educational value of the exhibit. This popular outreach tool for NOAA continues to be installed in museums, universities, labs, and visitor centers around the world. SOS serves as a way to help NOAA inspire the next generation of scientists by engaging students in a wide variety of Earth system topics ranging from climate change to tsunamis to hurricanes. It also extends NOAA goals of an environmentally literate society that is able to make informed decisions.

It is estimated that SOS is seen by over 33 million people every year. For further information, visit http://sos.noaa.gov/What_is_SOS/

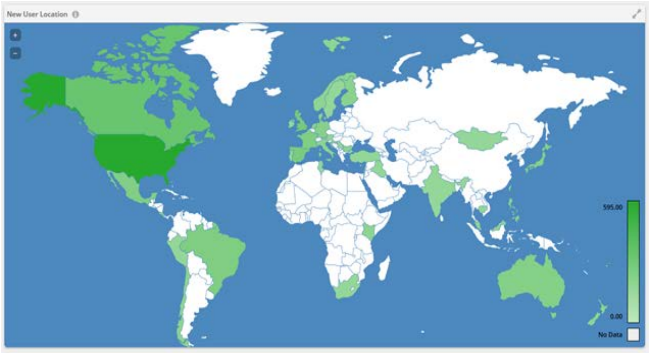


2. Science On a Sphere Explorer™ (SOSX)

Research Description: While Science On a Sphere has seen great growth in the last five years, there is still room for further expansion. In order to meet the needs of teachers and schools that aren't able to install a full Science On a Sphere exhibit in their schools, NOAA has developed SOS Explorer™ (SOSx), a desktop based version of SOS that can be used in classrooms and on personal computers. SOSx builds on the success of SOS and adds even more interactive capabilities. SOS Explorer™ uses the NOAA-developed TerraViz™ visualization engine to create an interactive Earth for a flat screen display including those projected on walls, computers, and large displays, providing teachers, students, and the public access to a library of selected Science On a Sphere® datasets and movies. The visualizations show information provided by satellites, ground observations and computer models and rapidly animate through real-time global data. In addition, tools included in the application allow users to zoom into, probe, and graph the data, as well as add supplementary material including websites, videos, pictures, and placemarks. In order to make the product more accessible for teachers, lesson plans and pre-programmed tours through standards-relevant topics are provided. For further information, visit http://sos.noaa.gov/SOS_Explorer/*Research to Applications:* The first public version of SOSx was released on September 1, 2015. This version comes with 15 datasets, three educational tours and supplementary lesson plans. It was featured on the NOAA and OAR homepages after its release, in addition to appearing in news articles, blogs, and social media. Within two weeks of its release, SOSx had been downloaded and used by over 750 people in 44 countries.



Daily number of new users of SOSx within the first two weeks.



Locations of SOSx usage within the first two weeks of release.

Summary of GSD's Technology Transfer Projects

Research to Operations and Applications

GSD Tech Transfer Project Name	TRL	Date Transfer Started	Date Transfer Completed	Expected Transfer Date	Transfer to What Entity	Description of what is being transferred
Research Area: NUMERICAL WEATHER PREDICTION						
Rapid Refresh (RAP) Model v1	TRL 9		5.01.2012		NWS/NCEP/ EMC	RAPv1 replaced the Rapid Update Cycle (RUC) operational model, expanding the domain from CONUS to all of North America but maintaining resolution at 13-km. RAP uses the WRF-ARW and GSI community code. The RAP benefits users needing frequently updated short-range weather forecasts, including those in the US aviation community and US severe weather forecasting community.
Rapid Refresh (RAP) Model v2	TRL 9		2.25.2014		NWS/NCEP/ EMC	RAPv2 provides significant improvement over RAPv1, a 13-km resolution, hourly-updated, North American weather model. RAPv2 improves winds/upper-air forecasts, mid-level moisture, near-surface fields, and convective environments. The enhancements will benefitusers needing frequently updated short-range weather forecasts, including, those in the US aviation community and US severe weather forecasting community. Also used prominently for energy-related (especially renewable) forecast guidance.
Rapid Refresh (RAP) Model v3	TRL 8	1.01.2015		2.15.16	NWS/NCEP/ EMC	RAPv3 provides significant improvement over RAPv2 for summer/winter storm environment, advanced physics with WRFv3.6, assimilation, and improved initiation conditions for HRRR.
High Resolution Rapid Refresh (HRRR) Model v1	TRL 9		9.30.2014		NWS/NCEP/ EMC	The HRRR is a NOAA real-time 3-km resolution, hourly updated, cloud-resolving, convection-allowing atmospheric model, initialized by 3km grids with 3km radar assimilation over a 1-h period, adding further detail to the HRRR initial conditions otherwise determined by the hourly data assimilation from the 13km radar-enhanced RAP model. It will provide significant improvement in convective forecasts.
GSD Tech Transfer	**TRL**	**Date Transfer**	**Date Transfer**	**Expected Transfer**	**Transfer to What**	**Description of what is being transferred**

Project Name		Started	Completed	Date	Entity	
High Resolution Rapid Refresh (HRRR) Model v2	TRL 8	1.01.2015		2.15.16	NWS/NCEP/ EMC	HRRRv2 provides significant improvement for summer/winter storm environment, in surface forecasts, and advanced physics.
WRF-Chem Model	TRL 7	1.01.2000			U.S.Air Force, Other Countries Weather Agencies	WRF-Chem is the Weather Research and Forecasting (WRF) model coupled in-line with atmospheric chemistry. This international community-developed 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. Coupled with the HRRR model, the experimental HRRR-Chem provides real-time predictions for smoke transport from wildfires that are used by the National Interagency Fire Center.
North American Rapid Refresh Ensemble (NARRE) and the High-Resolution Rapid Refresh Ensemble (HRRRE)	TRL 7	2010		2017 - 2019	NWS/NCEP/ EMC	GSD is working with the NWS/EMC and DTC to develop the North American Rapid Refresh Ensemble (NARRE) as an hourly-updated ensemble related to the current 6- 8-member SREF (Short Range Ensemble Forecast) now running at NWS. According to the EMC roadmap, the new 6-member NARRE is scheduled for operational implementation in 2017. (Currently, a preliminary time-lagged version of NARRE using multiple RAP members initialized at different times is running at NCEP). After 2017, the next implementation will be for the HRRRE to provide 3-km, hourly updated probabilistic forecast guidance. An experimental time-lagged HRRRE has been running in real time, producing thunderstorm probability grids which have been delivered to the Aviation Weather Center (AWC) and Storm Prediction Center (SPC) for the last 3 years. Over the next three years the work will advance to enable a transition of HRRRE (or High-Resolution Ensemble Forecast - HREF) to operations in 2019.
GSD Tech Transfer	**TRL**	**Date Transfer**	**Date Transfer**	**Expected Transfer**	**Transfer to What**	**Description of what is being transferred**

Project Name		Started	Completed	Date	Entity	
High Impact Weather Prediction Project: Knowledge/reports	TRL 6	4.01.2013		2.28.2016	NWS/OD	Reports documenting testing and demonstration results as a key component to inform research and operational weather modeling communities regarding selection of optimal global model dynamical core for NOAA next generation global prediction systems. http://hiwpp.noaa.gov/docs/HIWPP_Report- Year1-final-withAppendices-v2.pdf. HIWPP has also run an Open Data Initiative in 2015-16 to provide experimental real- time global forecast data to the community
Hazardous Weather System for U.S. Space Centers--Air Force Range Standardization and Automation(RSA)/AWI PS and LAPS	TRL 8	2001	Ongoing	2014	USAF Vandenberg Air Force Base	USAF Launch Weather Officers at Vandenberg AFB required a completely integrated, cost-effective, local data assimilation and forecasting system with an integrated weather display to support space launch range operations. GSD was tasked to develop ingest and display (based on AWIPS) of several local datasets and to use those data in GSD LAPS (Local Analysis and Prediction System) to initialize the model, and provide tools to help the weather officers prepare and communicate weather information to Range personnel for launches. GSD continues to work with the USAF to update this system on a regular basis.
Global Precipitation Measurement (GPM) Product Assessment	TRL 5	10.01.2013	9.30.2015	Report submitted to NESDIS	JCSDA/NASA	Provide summary report to NESDIS on the evaluation of the utility of PMM (GPM + TRMM) space-based radar data for initializing a weather forecasting model. The GPM satellite system consists of a core satellite and a constellation of additional satellites. The use of radar in combination with microwave sensors will also be considered. This assessment is one piece of information that helps guide the development process to improve the observation products from these satellites.
Global Positioning System Meteorology (GPS-Met Data)	TRL 8			2016	Commercial contractor	The Global Positioning System Meteorology (GPS-Met) observing system project develops and assesses techniques to measure atmospheric water vapor amounts using ground-based GPS receivers. Estimates of the total column precipitable water (TPW) are assimilated into NWS operational weather prediction models and used to fill observation gaps in weather satellite products generated by NESDIS. Assimilation of these water vapor or precipitable water estimates has been shown to significantly improve the accuracy of hourly weather forecasts.

						Completed in June 2015, the GSD CRADA demonstrated that commercial vendors can meet NWS requirements for atmospheric water vapor data used in operational models and For nowcasting. NWS was able to obtain the GPS-Met (ground- based GPS-meteorology) data through the one-year Mesonet Data Buy contract and will perform an initial assessment of the quality of the data in Q1 of FY16. At the same time, NWS will begin a more robust, fully competed, multi-year procurement process in first quarter of FY16 to only purchase the GPS- Meteorology data that will have more detailed requirements and quality thresholds. GSD will play a role in the transition after a contract is awarded.

Research Area: DECISION SUPPORT

GSD Tech Transfer Project Name	TRL	Date Transfer Started	Date Transfer Completed	Expected Transfer Date	Transfer to What Entity	Description of what is being transferred
Hazard Services Tool	TRL 7	2009	Ongoing	2017	NWS/WFOs	The Hazard Services Tool integrates several software tools into a common interface for issuing timely and accurate hazard information and building a two-way communication platform for collaboration among all decision-makers. It was made available in the AWIPS II September 2015 release in a "practice mode" setting for NWS forecasters and test sites to use and provide feedback to GSD developers.
GFE Tools for NCEP National Centers	TRL 7	2012	Ongoing	2020	NWS/NCEP	Streamlining the forecast process at the NCEP National Centers to produce gridded forecasts replacing outdated methodologies.
FDSE Decision Support Tools	TRL 6	2012	Ongoing	2017	NWS/WFOs	For the NWS Forecast Decision Support Environment (FDSE) project, develop three decision support components: Gridded Forecast Monitor, Short-Term Update Techniques, and an Ensemble Tool
GSD Integrated Support for Impact Air Traffic Environments (INSITE)	TRL 6	2011	Ongoing	2017	NWS/NEXTGEN/IDP	The Integrated Support for Impacted air-traffic Environments (INSITE) prototype provides guidance to NWS forecasters by combining weather and traffic data to produce detailed information on the potential impacts of forecast convective weather to en-route aviation operations.
GSD Tech	**TRL**	**Date**	**Date**	**Expected**	**Transfer**	**Description of what is being**

Transfer Project Name		Transfer Started	Transfer Completed	Transfer Date	to What Entity	transferred
Aviation Weather Forecast Product Assessments	None	2000	Ongoing	Technical Reports submitted regularly to NWS and FAA	FAA and NWS	As part of the evaluation process for transitioning new aviation weather products into operations, GSD is often tasked by NWS and/or FAA to conduct new product assessments to help determine their operational viability. Technical reports are developed and issued or presentations of the findings are given to NWS and/or FAA.
Real-Time Verification System (RTVS)	TRL 8	1996	Ongoing	None	Used for NWS operations	The Real-time Verification System (RTVS) is an outdated tool for assessing the quality and effectiveness of weather observations, warnings, and forecasts, and is maintained by GSD. Although there are no plans by NWS to transition RTVS to operations, the NWS/Aviation and Space Weather Services Branch continues to fund its operation and maintenance at GSD. GSD provides monthly reports of verification statistics from RTVS for product performance tracking.
Event-Based Verification and Evaluation of NWS Gridded Products Tool (EVENT)	TRL 6	2011	Ongoing	2018	NWS/NEXTGEN/IDP	EVENT is an automated web-based tool that provides ongoing performance measures of NWS gridded products with respect to their ability to forecast events impactful to aviation operations.
TRACON Gate Forecast Verification Tool	TRL 5	2015	Ongoing	2018	NWS/NEXTGEN/IDP	The automated production of TRACON Approach and Departure gate forecasts has been centralized for a subset of CWSUs. The automated tool, produced and operated by AWC, also allows for forecaster-over-the-loop updates to the automated output. Work in 2015/16 included extension of the tool to include verification of the forecast output as modified by the CWSU forecaster, as well as preparatory activities for the transition of the GSD verification tool to NWS operations.
CWSU Briefing Tool	TRL 7	2015	Ongoing	2019	NWS/NEXTGEN/IDP	NWS meteorologists at 21 Center Weather Service Units (CWSUs) provide decision support services at FAA Air Route Traffic Controller Centers (ARTCCs). The CWSU meteorologists provide routine and on-demand briefings containing weather forecast information critical to FAA Traffic Flow Management (TFM) decisions. In 2015/16, GSD completed the development of an automated tool for all 21 CWSUs for terminal winds. Work for 2016/17 will include developing ceiling and visibility capabilities for a CWSU focus group.
GSD Tech	**TRL**	**Date**	**Date**	**Expected**	**Transfer**	**Description of what is being**

Transfer Project Name		Transfer Started	Transfer Completed	Transfer Date	to What Entity	transferred
GFE to Australian Bureau of Meteorology	TRL 9	2006	2012		Australian Bureau of Meteorology	Graphical Forecast Editor (GFE) tool was redesigned to meet the requirements of the Bureau of Meteorology (BOM) in Australia. After several years of development, they have deployed their version of GFE across their entire country and are using it for weather forecast operations.
FX-Net System	TRL 9	2001	2013		NWS Regional Offices	The FX-Net system uses the Internet to provide full AWIPS visualization and data analysis capability with a Graphical User Interface (GUI) that closely emulates the standard AWIPS I workstation, allowing the National Weather Service (NWS) Incident Meteorologists (IMETs) to move seamlessly between their Weather Forecast Offices (WFO) equipped with the AWIPS system to FX-Net in the field. This system was fully transitioned to NWS Regional Office ownership in 2013.
Gridded FX-Net Tool	TRL 8	2007	Ongoing	Used regularly in operations	BLM/USFS/ NIFC	The US Forest Service and the Bureau of Land Management use GSD's experimental Gridded FX-Net tool to develop and execute fire potential algorithms used to rate fire danger indexes. Gridded FX-Net allows the National Interagency Fire Center (NIFC) Predictive Services forecasters to retrieve model grids which are applied to specialized fire prediction and fire danger models. Products from these models provide the USFS, BLM and other land management agencies with long-range resource planning and fire management decision support information.
FX-CAVE Workstation	TRL 6	2015	Ongoing	Limited use in operations	BLM/USFS/ NIFC	The FX-CAVE workstation is the next generation of meteorological workstation based on the NWS AWIPS II CAVE workstation. It will eventually make the FX-Net System obsolete. The National Interagency Fire Center (NIFC), and its eleven field offices, are transitioning to FX-CAVE System starting in 2015. Agreements are in place to proceed indefinitely with this interagency cooperation.
Evaluation of Earth Networks Total Lightning Products	TRL 7	2014	Ongoing	2017	NSSL	GSD is doing the programming to provide the ability to display the Earth Networks total lightning data set on AWIPS-II so it can be evaluated for its utility for initializing weather forecast models.
GSD Tech	**TRL**	**Date**	**Date**	**Expected**	**Transfer**	**Description of what is being**

Transfer Project Name		Transfer Started	Transfer Completed	Transfer Date	to What Entity	transferred
HFIP Consolidated Display of Products	TRL9	2012		2016	NWS	After Hurricane Katrina, Congress provided significant research funding too many organizations for better hurricane prediction. NOAA's HFIP program provided funds to GSD to develop a website which consolidates and centralizes the products from different experimental and operational weather and hurricane models and effectively displays them in uniform formats for comparison. The website displaying the various HFIP products is used by National Hurricane Center (NHC) forecasters, NWS managers, and FEMA managers as a quasi-operational forecasting tool for tropical weather events. GSD continues to maintain the website but anticipates that it will transition to NWS O&M.
Research Area: ADVANCED TECHNOLOGIES AND OUTREACH						
MADIS Real-Time system; Data Recovery system; Data Archive system	TRL 9	2010	1.21.2015		NWS/NCEP/ NCO	MADIS Initial Operating Capability (IOC) at NWS/NCEP/NCO was completed 9/30/2010. ESRL/GSD's responsibility for the MADIS real-time system, the MADIS Data Recovery System, and MADIS Data Archive system was completed 12/31/2014. After NWS testing, Final Operating Capability (FOC) was achieved 1/21/15.
MADIS Improvement Process for Operations	TRL 4	2015	Ongoing	Ongoing	NWS/NCEP/ NCO	NOAA has the ability to better use non-NOAA provided weather data to improve the understanding of current conditions and improve hazardous weather forecasts. Non-NOAA provided mesonet data fills gaps and supplements NOAA's investment in the National Mesonet (NM) program. Improvements to these data sets will provide a backup and supplement NOAA's NM investment. The improvement process would analyze and develop improved pathways for acquiring and disseminating non-NOAA data for use by NWS operations. Standard, unified, internet-based tools for capturing and maintaining metadata would be built into MADIS. Through these improvements new data in MADIS would be of higher quality and more quickly assimilated into NWS operations. Acquiring new observations that are useable by NOAA, which sometimes takes years, would be near instantaneous.
GSD Tech	**TRL**	**Date**	**Date**	**Expected**	**Transfer**	**Description of what is being**

Transfer Project Name		Transfer Started	Transfer Completed	Transfer Date	to What Entity	transferred
Transition of Clarus to MADIS	TRL 6	2015		09.30.2016	NWS/NCEP/ NCO	Clarus is a research and development system run by the Federal Highway Administration to demonstrate and evaluate the value of "Anytime, Anywhere Road Weather Information" provided by both public agencies and the private weather enterprise to transportation users and operators. The Federal Highway Administration (FHWA), NWS, and the Office of Oceanic and Atmospheric Research (OAR) agreed that MADIS should become the operational home for Clarus. The objective is to incorporate Clarus system functionality into the MADIS system so that transportation users and operators don't lose the Clarus capabilities they have grown to rely on to help with transportation decision support issues.
Transition of HADS/AFWS to MADIS	TRL 6	2015		9.30.2016	NWS/NCEP/ NCO	Data from HADS and AFWS will be transitioned into MADIS. The Hydrometeorological Automated Data System (HADS) is a real- time and near real-time data acquisition, processing, and distribution system operated by the National Weather Service to support the Flood and Flash Flood Warning programs administered by the Weather Service Forecast Offices and the operations performed at River Forecast Centers. HADS created data products bolster several other NWS program areas including fire weather support services, local and national analysis of precipitation events, hydrologic modeling, and the verification of NEXRAD precipitation estimates. The Automated Flood Warning Systems (AFWS) network connects numerous local flood–warning systems, and integrates and shares information from 1700 sensors in 12 states.
Science On a Sphere Installations and Development	TRL 9	2004	Ongoing	Ongoing	Various commercial, non-profit, and government entities	Considered R2U for 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. The captivating display is in demand by science centers, museums, universities, schools, science conferences, and other venues and can display over 475 scientific datasets. As of August 14, 2015, over 119 permanent installations of Science On a Sphere are operating in 22 countries around the world. GSD continues to infuse SOS with new technologies to enhance its educational impact.

GSD Tech Transfer Project Name	TRL	Date Transfer Started	Date Transfer Completed	Expected Transfer Date	Transfer to What Entity	Description of what is being transferred
Science On a Sphere Explorer	TRL 8	9.07.2015	Ongoing	Ongoing	Educational Institutions and the Public	NOAA has the ability to build a more resilient public by bringing its SOS experience to classrooms throughout the Nation via Internet. NOAA's vast collection of data is often difficult for teachers and students to find, understand, and incorporate into classroom lessons. SOS Explorer (SOSx) provides a single access point to a large collection of Earth system visualizations and provides analysis tools to better understand them. This increased understanding helps to engage students, encourage them to pursue careers in science, and foster better stewardship and decision making.
Central Weather Bureau (CWB) in Taiwan Tech Transfers	TRL 8	2000	Ongoing	Ongoing	CWB	GSD coordinates a collaborative program between the NOAA weather community and the Central Weather Bureau in Taiwan, sponsoring its guest weather researchers and forecasters engaged in developing CWB's Weather Information and Nowcasting System (WINS) and working collaboratively on weather applications to benefit both NOAA and CWB weather communities. GSD tech transfers examples: 2011--Prototype of GFE/Hazard Services software for AWIPS; 2012--evaluation of the performance of NOAA's HWRF model over the Western Pacific area; 2013--GPS-Met data assimilation and real-time evaluation; 2014--AWIPS II Development Environment training 2015--GFE smart tools for CWB's text formatter development
CWB AWIPS-II Conversion	TRL 4	10.01.2014		9.30.2016	Central Weather Bureau, Taiwan	Assist CWB with conversion from AWIPS I to AWIPS-II and the development of high-resolution product generation assistance tools.
Fortran GPU Compiler	TRL7	2009		2016	Commercial vendors	The F2C-ACC compiler was developed by GSD from 2009-2012 to support the parallelization of the NIM for NVIDIA GPUs. GSD works with vendors (such as Cray, PGI, Intel) to identify and address their compiler performance issues by sharing F2C-ACC, code and expertise. It has since become the standard by which commercial compilers are judged, and an effective vehicle to gain important and substantial improvements in the openACC compilers. NWS operations will ultimately benefit from GSD's work to ensure procurement of fast and efficient commercial GPU compilers.
GSD Tech	**TRL**	**Date**	**Date**	**Expected**	**Transfer**	**Description of what is being**

Transfer Project Name		Transfer Started	Transfer Completed	Transfer Date	to What Entity	transferred
NEIS and TerraViz	TRL 6	2012		To Be Determined	Other NOAA Line Offices; Private Sector	Through the High Impact Weather Prediction Project (HIWPP), NEIS is providing interested parties (i.e. NOAA researchers, private companies, and the public) research grade near real- time data delivery and visualization using TerraViz allowing them to compare and analyze research models results. A patent application was filed for this technology.

Key

Technical Readiness Levels (TRL) Definitions

TRL 1 Basic principles observed and reported

TRL 2 Technology concept and/or application formulated

Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 4 Component/subsystem validation in laboratory experiment

TRL 5 System/subsystem/component validation in relevant environment

System/subsystem model or prototyping demonstration in a relevant end-to-end environment

TRL 7 System prototyping demonstration in an operational environment

Actual system completed and "mission qualified" through test and demonstration in an operational environment.

TRL 9 Actual system "mission proven" through successful mission operations