K. Technologies transferred to operations and assessment of their significance/impact on operations

Radar Technology Transfer

National Severe Storms Laboratory (NSSL) scientists have been transferring weather radar technology to operations for more than four decades. Their research led to the Next Generation Radar (NEXRAD) WSR-88D network of 160-plus Doppler weather radars. Previous research provided enhancements that improved the older WSR-57 network before its replacement by NEXRAD.

NSSL scientists were the first to discover the tornadic vortex signature and develop a detection algorithm for it and the mesocyclone. They were the first to operationally test use of Doppler radar for tornado and severe thunderstorm warnings (Joint Doppler Operational Project (JDOP), 1977-1979).

NSSL developed large segments of the original NEXRAD training materials and delivered many classroom lectures, in association with the National Weather Service (NWS) Warning Decision Training Branch (WDTB). Based on applied research with newly-installed WSR-88D radars and input from basic research (i.e. Verification of the Origins of Rotation in Tornadoes Experiment 1 known as VORTEX1), NSSL prepared three Tornado Warning Guidance documents for the NWS.

NSSL scientists developed a guide for pilots entitled, “Microbursts: A Handbook for Visual Identification.” The book was published in 1989 prior to TDWR as a mitigator for downburst-caused airline accidents. NSSL scientists prepared several documents to help in the training of Doppler velocity interpretation, including “A Guide for Interpreting Doppler Velocity Patterns” and a chapter on Doppler velocity interpretation for the Federal Meteorological Handbook (FMH) 11.

When the NEXRAD original proprietary hardware became obsolete, NSSL designed and implemented an Open Systems Radar Product Generator (ORPG) to meet the expanding needs of the WSR-88D network. In addition, NSSL prototyped the Open Radar Data Acquisition (ORDA) system and designed and built an Open Principle User Processor (OPUP) for use by the Air Force.

NSSL developed the NEXRAD velocity dealiasing algorithm that was installed at the time of initial radar deployment, an algorithm, with NSSL updates, that is still used in NEXRAD today. In addition, NSSL developed a Multi-PRF Dealiasing Algorithm (MPDA) and new scanning strategy (VCP 121) that have been implemented on NEXRAD.

Many of the original algorithms in the NEXRAD WSR-88D were developed at NSSL. They were then improved and implemented in the ORPG. These algorithms were included:

- Mesocyclone detection algorithm (MESO and MDA)
- Tornadic Vortex Detection Algorithm (TVS and TDA)
- Hail detection algorithm (Hail and HDA)
- Storm Cell Identification and Tracking (SCIT and Filtered SCIT).

NSSL has developed several severe storm algorithms that will be run on the Terminal Doppler Weather Radar (TDWR) radars as their output is brought into the NWS Advanced Weather Interactive Processing System (AWIPS)and routine NWS use in warning and forecast operations.

To obtain the high-resolution moment data (Level II) for research and operational use, NSSL and co-project leaders at the University of Oklahoma (OU) collaborated with the Radar Operations Center (ROC), University Corporation for Atmospheric Research (UCAR) and National Climatic Data Center (NCDC) to archive and distribute the data in a demonstration project call Collaborative Radar Acquisition Field Test (CRAFT). CRAFT built upon NSSL technology used to communicate with the WSR-88D high-resolution data feed called the Radar Interface and Data Distribution System (RIDDS).

To gain input on early WSR-88D radar functionality and first-generation NSSL algorithms installed on WSR-88D radars, NSSL formed and hosted a tri-agency (NWS, Air Force Weather Agency (AFWA), and Federal Aviation Administration (FAA)) WSR-88D user group that met many times during the 1990s and was instrumental in establishing the need for and design of NSSL technology transfer applications for NEXRAD.

The Warning Decision Support System (WDSS) was first developed in the early 1990s to support implementation and testing of new single radar algorithms. WDSS was used operationally at several NWS offices to display high-resolution output from multiple radars. A multi-radar, multi-sensor version was later developed called the Warning Decision Support System – Integrated Information (WDSS-II). Several ideas developed in this system have been transferred to the NWS AWIPS system: WDSS-II was implemented for the System for Convective Analysis and Nowcasting (SCAN); the Four-Dimensional Stormcell Investigator (FSI) that produces real-time vertical slices and Constant Altitude Position Plan Indicators (CAPPIs) was transferred to AWIPS, and is also being used in the Center for the Adaptive Sensing of the Atmosphere (CASA) system.

Products from WDSS-II are distributed on the internet in support of AWIPS and N-AWIPS operations. An off-line version called WSR-88D Algorithm Testing and Display System (WATADS) has been used by NWS forecasters and others for developing their own radar applications.

A WDSS-II algorithm control system was developed to allow algorithms to run on many different radars at one time within NSSL (i.e. start, stop, log, etc.).

NSSL scientists adapted the Velocity Azimuth Display algorithm and the VAD wind profile display for NEXRAD Doppler radar use.

NSSL is working in collaboration with the NWS Warning Decision Training Branch (WDTB) to develop a tool (VCP Explorer) to help forecasters visualize the interaction of a radar beam path with the terrain surrounding the radar.

NSSL developers wrote a new Human Computer Interface (HCI) that was implemented in the ORPG and replaced the Unit Control Position, improving the usability of several WSR-88D features including adjustment of the Pulse Repetition Frequency.

NSSL scientists developed a gust front algorithm for the identification of gust fronts and a damaging downburst algorithm and tested them in the NWS office in Phoenix, AZ. Parts of these algorithms are implemented on the Federal Aviation Administration's Terminal Doppler Weather Radar (TDWR).

For the entire NEXRAD period, and now continuing, NSSL has maintained and is adding to a robust database of operational WSR-88D radar and experimental system (e.g. KOUN dual-polarization) data sets. These data sets include environmental observation data, numerical model data, and verification information. The database is diverse with respect to areas of the United States and hazardous weather types (i.e. severe convective storms, winter storms, flash floods, land-falling hurricanes, etc.). The database is used by NSSL, ROC, and university scientists for applications development and testing.

NSSL “On-Demand” Severe Storm Verification system, funded by the National Oceanic and Atmospheric Administration (NOAA) High-Performance Computing and Communications Program (HPCC) is a web-based query tool designed to help National Weather Service meteorologists quickly verify their severe thunderstorm and tornado warnings. This system uses two new algorithms developed by NSSL: the Maximum Expected Size of Hail (MESH) and the rotation tracks obtained from the linear least squares vorticity estimations.

The Severe Hazards Analysis and Verification Experiment (SHAVE) is a unique project that blends high-resolution radar data with geographic information. The primary objective of this experiment is to collect high temporal and spatial resolution data that describe the distribution of hail sizes, wind damage and flash flooding produced by severe thunderstorms. SHAVE has been adopted by numerous NWS Offices to improve verification of severe weather events.

NSSL developed and tested a “Rapid Update” system that produced algorithm output on every elevation scan instead of at the end of a volume scan, giving faster updates for the Mesocyclone, Tornadic Vortex Signature, and SCIT. The MDA and TDA rapid updates were implemented in the WSR-88D system. NSSL Collaborated with National Center for Atmospheric Research (NCAR) on their Weather Support to Deicing Decisions Making System (WSDDM) by providing real-time radar calibration data.

NSSL scientists have long worked to reduce/eliminate the “Doppler dilemma” – long (short) range of coverage gives small (large) velocity measurement interval. Range/velocity ambiguities arising from the dilemma were reduced for initial NEXRAD deployment by introducing separate scans for reflectivity and velocity estimation. This solution created regions where velocity estimates could not be made, so-called areas of “purple haze.” To help eliminate “purple haze”, NSSL scientists have more recently developed phase coding and staggered Pulse Repetition Times (PRT). Phase coding has already been installed on WSR-88Ds, and staggered PRT will be introduced soon. These changes have the potential to all but eliminate WSR-88D range/velocity ambiguities.

NSSL has provided a corrected spectrum width estimator so that its computations are unbiased. The new estimator is in the process of being deployed on all WSR-88D radars.

NSSL has created Super Resolution data (250 m range gates and 0.5 deg azimuths) for products for forecaster use and re-combined data (1 km range gates (where needed) and 1.0 deg azimuths) for use by the current algorithms. NSSL is currently working on versions of the algorithms tailored to the use of Super Resolution data. As they are completed, they will be implemented on the WSR-88Ds to replace the current algorithms.

Several new Volume Coverage Patterns (VCPs) have been proposed, tested and implemented on the WSR-88Ds including VCP 12 to increase the low-level vertical resolution and decrease the time between volume scans to approximately 4 minutes.

Research has continued on visualization techniques including iso-surface display and real-time volume navigation. In addition, products are available in Google Earth.

Much research has been accomplished with applications to hydrometeorology. They include a radar reflectivity quality control product that has significantly improved very short-term Quantitative Precipitation Forecasts (QPFs) in the operational Rapid Update Cycle (RUC) model, 3-D radar reflectivity mosaic technique, multi-sensor Quantitative Precipitation Estimate (QPE) version 2 (Q2) products with automatic precipitation classification, and a Radar Reflectivity comparison tool used by the ROC extensively to assess real-time performance of the WSR-88D network.

A Quality Control (QC) algorithm for the NEXRAD Doppler Velocity data has been developed for use by National Centers for Environmental Prediction (NCEP).

Research in dual-polarization weather radars is leading to the implementation of dual-polarization on the WSR-88D. Over this time, researchers have developed dual-polarization algorithms including the hydrometeor classification, melting layer and rainfall accumulation algorithms, enhanced the dual-polarization sensitivity, worked on the calibration of both differential reflectivity and phase and provided dual polarization measurements at low Signal to Noise Ratios (SNR). With the additional dual-polarization fields, a new format for archive II data was collaboratively developed.

NSSL collaboratively looked at ways to support the NWS during radar outages using the Shared Mobile Atmospheric Research & Teaching Radar (SMART-R) systems (mobile C-Band Doppler radars) and satellite transmission of the data. Also using the same techniques to support Debris-Flow experiments in California, data is uplinked and used in Q2 for real-time warning decisions by the NWS.

NSSL worked with the NWS in Monterrey, CA to provide commercial television radar information (KPIX) for use in a Weather Forecast Office to cover an area not seen well with the WSR-88D.

NSSL provided hardware to implement Doppler capabilities on the NOAA P-3 aircraft along with improved scan strategies and coordination activities during various field experiments.

On-going research has resulted in a new and improved distributed signal processing Linux PC Cluster that provides a scalable processing capacity for meeting the needs of our weather radar research using the National Weather Radar Testbed – Phased Array. New clutter identification and removal schemes as well as faster data acquisition methods such as over-sampling and whitening and beam multiplexing have been developed.

Lightning Technology Transfer

NSSL developed a lightning threat algorithm for Weather Data Inc. using current lightning and radar data and a radar nowcast product to predict the lightning strike possibility.

NSSL developed displays of total lightning mapping for use by forecasters in the Weather Forecast Office (WFO) and Storm Prediction Center (SPC).

NSSL evaluated Cloud to Ground (CG) lightning mapping technologies for the Office of the Federal Coordinator for Meteorological Services (OFCM) and combined NSSL network to produce the first national network for CG mapping. CG mapping data is used extensively in aviation weather, fire weather, FAA terminal operations, various Department of Defense (DOD) applications, and by the National Aeronautical and Space Administration (NASA) in launching the space shuttle.

Model simulation studies and analysis helped justify inclusion of an optical lightning mapper on Geostationary Operational Environmental Satellite R-Series (GOES-R).

NSSL established that stratiform precipitation regions of mesoscale convective systems are highly electrified and that anvils of severe storms are also highly electrified. These have had important implications for shuttle and rocket launch criteria and safety of personnel at the Kennedy Space Center since lightning flashes can occur several tens of kilometers from the storms.

NSSL collaborated with the University of Oklahoma to develop the most advanced cloud model incorporating lightning and electrification processes.

NSSL showed that lightning flash rates are correlated with various storm parameters related to severity.

NSSL developed mobile laboratories and mobile ballooning including upper air measurements used in operational forecasts, and cutting edge communication systems used to transmit data from the field back to operational forecasters.

Numerical Modeling Technology Transfer

NSSL scientists led in the initial evaluation and further development of Short-Range Ensemble Forecasting (SREF) to benefit NWS operations in collaboration with NCEP. SREF is now a routine part of the operational forecast system and is heavily used by the SPC in the production of outlooks.

An algorithm for assimilating cloud-to-ground and total lightning data into mesoscale models was developed for the US Navy for use in the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS).
NSSL scientists led in the operational implementation of the Kain-Fritsch convective parameterization scheme in the operational SREF, with specialized output available to SPC forecasters. The scheme is used worldwide at various modeling centers (NCAR, NCEP, US Navy, US Air Force, Japanese Meteorological Agency, and Environment Canada).

A 3.5D variational (3.5DVAR) radar data assimilation package was developed in collaboration with scientists at OU/Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) and Naval Research Laboratory (NRL) Monterey. This package has been successfully tested with the Navy's COAMPS model for improving predictions of high-impact weather and will be implemented into Navy shipboard operations.

A radar data quality control (QC) package has been developed and improved in collaboration with scientists at OU/CIMMS, NCEP and NRL. The Y2007 version has been installed into the Navy's nowcast system for processing real-time radar data and was delivered to NCEP where it is being implemented for operational use.

A 2D variational (2DVAR) radar wind analysis package was developed in collaboration with scientists at OU/CIMMS to retrieve real-time vector wind fields from WSR-88Ds. This package has been selected for real-time implementation over major urban areas by the Biological Warning and Incident Characterization program supported by the US Department of Homeland Security.

Forecast Technology Transfer

NSSL developed an operational algorithm, called "Mesoscale Convective System (MCS) maintenance probability", to forecast the longevity of severe convective systems in collaboration with the SPC. The algorithm has been transferred to NWS forecast offices through the AWIPS data stream.

Stand-alone versions of the Kain-Fritsch and Betts-Miller-Janjic convective schemes have been incorporated into the SPC's "NSHARP" sounding analysis program to assist in sounding diagnostics. This enhanced sounding analysis program has been shown to be very valuable to SPC forecasters in defining the severe weather threat.

NSSL scientists were the first to establish that cloud-to-ground lightning flashes lowering positive charge to ground (+CG flashes), instead of the usual negative charge, can occur naturally in severe storms and can be an indicator of storm severity. This result has spurred a great deal of on-going research on what inferences can be drawn about the storms in which these flashes are observed.

NSSL developed a practically perfect forecast verification scheme for the Storm Prediction Center, which is used for operational forecast verification.

NSSL developed local daily climatological probabilities of severe thunderstorm hazards in the US, which are used in SPC forecasts and by risk assessment groups. In addition, they developed climatologies for heavy rainfall events and derechos that are used by NWS forecasters.

Conceptual models of the physical processes associated with severe weather events have been developed or expanded by NSSL scientists and are routinely used by NWS forecasters. These conceptual models include conditional symmetric instability, moisture convergence and convective initiation, dryline evolution and convective initiation, derecho longevity, electrical structures of severe storms and convective systems, flash flood forecasting, Gulf of Mexico return flow, severe weather environmental sounding diagnosis and parameter evaluation (including helicity), and tornadogenesis.

Conceptual models of an ingredients-based forecasting process have been developed by NSSL scientists and routinely used by NWS forecasters.

Satellite-based products such as mesoscale winds (upper-level), fire locations, surface wetness, winter precipitation efficiency, and MCS tracking have been made available to the SPC and National Environmental Satellite, Data, and Information Service (NESDIS) Satellite Analysis Branch. Forecasters have used these products to provide national guidance regarding severe storms and fire weather.

VORTEX1 produced a number of forecast-related technology transfer outputs, in addition to the warning-related technology transfer outputs mentioned in the Radar Technology Transfer section. The warning-and-forecast-related outputs were transferred to operational NWS use through WDTB training materials (Tornado Warning Guidance Training issued In 1997, 1999, and 2002), and through formal publications and public presentations by NSSL scientists. Important forecast guidance from VORTEX1 included: 1) large variability in low-level shear, buoyancy, and other variables that were observed on storm scales, but were not observable on larger-scale observations commonly available to warning forecasters, 2) higher values of environmental, sub-cloud relative humidity greatly aided potential tornadogenesis by reducing cold-air production in storm downdrafts and preventing outflows from becoming too-strong, and 3) shallow, small-scale boundaries and baroclinic zones (arising from outflows from preceding storms, cloud-cover-to-sunshine zones, anvil shadows, and other sources) produced enhanced storm-relative helicity on their cool sides and were associated with many observed instances of tornadogenesis.

Important forecast guidance from VORTEX2 included: 1) Tornado strength winds can sometimes extend far outside the visible condensation funnel. 2) Correlations between different raw and derived data have been seen. 3) A new feature has been discovered: a low-reflectivity ribbon has been observed to "cut" through the hail core through a significant depth of the storm and "points" to the tornado. 4)Tornadogenesis is not always a top-down process. Mid-level and low-level processes might both be at work to produce a tornado.

Hydrometeorology Technology Transfer

In an effort to improve radar derived rainfall estimates, NSSL scientists developed a WSR-88D evaluation tool, called the "Radar Reflectivity Comparison Tool or RRCT, to monitor in real-time the radar echoes from all WSR-88D radars to ascertain potential calibration offsets and transmitter drift by comparing reflectivity at similar altitudes and ranges from overlapping radars. The tool has a web-based interface that allows the analyst to select the level of integration from hours to months, over which the comparison takes place. It is used by the NWS Radar Operations Center in daily operations.

NSSL scientists have developed a real-time system to develop, test, and assess advance techniques related to precipitation estimation. The system, called Q2, integrates radar information provided by the national WSR-88D radar network, FAA Terminal Doppler Weather Radars, and Canadian weather radars to provide a seamless rainfall estimate every 5 minutes across the continental US. Q2 components include a quality control module, a data integration module, and a precipitation estimation module. Q2 is being transitioned to the NWS for use in model assimilation of radar information.

The Coastal and Inland Flooding Observation and Warning (CI-FLOW) project is a demonstration projection that predicts the combined effects of coastal and inland floods for coastal North Carolina. CI-FLOW captures the complex interaction between rainfall, river flows, waves, and tides and storm surge, and how they will impact ocean and river water levels. NSSL, with support from the NOAA National Sea Grant, leads the large and unique interdisciplinary team.

The Flooded Locations And Simulated Hydrographs Project (FLASH) was launched in early 2012 to improve the accuracy and timing of flash flood warnings. FLASH uses forecast models, geographic information, and real-time high-resolution, accurate rainfall observations from the NMQ/Q2 project to produce flash flood forecasts at 1-km/5-min resolution. FLASH project development continues to be an active collaboration between members of NSSL's Stormscale Hydrometeorology and Hydromodeling Groups, and the HyDROS Lab at the University of Oklahoma.

Warning Technology Transfer

NWS forecasters participating in the NOAA Hazardous Weather Testbed (HWT), hosted by NSSL, have the opportunity to work with experimental tools, some of which are moved into operations. At the end of their visit, forecasters write about their impressions. Overall, they felt that the Multiple-Radar, Multiple Sensor (MRMS) system was considered to be “the most useful new product for warning operations.”

MRMS is a system with automated algorithms that quickly and intelligently integrate data streams from multiple radars, surface and upper air observations, lightning detection systems, and satellite and forecast models. Numerous two-dimensional multiple-sensor products offer assistance for hail, wind, tornado, quantitative precipitation estimation forecasts, convection, icing, and turbulence diagnosis.

Quotes from users:
"We use the rotational track products for storm surveys very frequently including the April 25, 2010 event. In fact, we have used the data for every tornado survey for the past several years, beginning in 2009. We begin looking at the data just as the event winds down so we can target our phone calls and begin planning for the damage survey. While conducting the damage survey, we will consult the rotational tracks product to being the search on the ground. - NWSFO in Raleigh, NC

"We are excited in that we expect to be able to get the rotational track and hail swath products from NSSL, in addition to a few others, into AWIPS sometime this summer. The data is from the NSSL Multi-Radar Multi-Sensor severe weather algorithm system (MRMS) and will be transmitted to our office via the ER LDM from NSSL. Getting this data in real time will open up even more opportunities for us. It will likely take a couple of years before this is data is baselined and sent over the SBN across the NWS but getting this data into our forecasters hands in an experimental manner in near real-time will be great."

"MRMS/Q2 provides precipitation estimates from portions of southwest Texas, western New Mexico, south central Colorado and Mexico where few if any other sources of precipitation data exist. This area has now experienced major flooding in two of the past four years due to dissipating tropical systems. The loss of Q2 would, in short, mean the loss of what we have seen to be our most accurate radar-based QPE." – Greg Story (West Gulf RFC).

"The MRMS system provides a flexible and efficient software computing architecture to accommodate rapid changes or additions to the NextGen objectives/requirements while providing a straight forward research-to-operations (RTO) integration platform for AWRP-funded, radar dependent, turbulence and icing solution portfolios without system dependencies or delays in implementation within the WSR-88D system.." – FAA Reduced Weather Impact (RWI) plan

"…3D cloud and hydrometeor fields are not well sampled by conventional observing systems and no single observing platform fully captures the needed information. The NSSL MRMS data have been absolutely critical to the success we had in the radar reflectivity data assimilation in the RUC, and its impact on the HRRR, and now in the RR." - Steve Weygandt (GSD)

"Even today, the volume of radar data alone is such that it is nearly impossible for a well-trained meteorologist to be assured they have interpreted all of the relevant information." - David Andra (WFO OUN SOO), commenting on the need for a robust data integration system to control the "fire hose" of multiple rapidly-updating data streams during WFO warning operations.

Other

mPING

NSSL collects public weather reports through a free app available for smart phones or mobile devices. The app is "mPING," or Meteorological Phenomena Identification Near the Ground. mPING reports are immediately archived into a database at NSSL, and are displayed on a map accessible to anyone.

Weather radars cannot “see” at the ground, so mPING reports are used by the NOAA National Weather Service to fine-tune their forecasts. NWS offices are “thankful for mPING” and use it to track precipitation types in winter weather, figuring out precipitation onset in areas of poor radar coverage, and for hail placement.