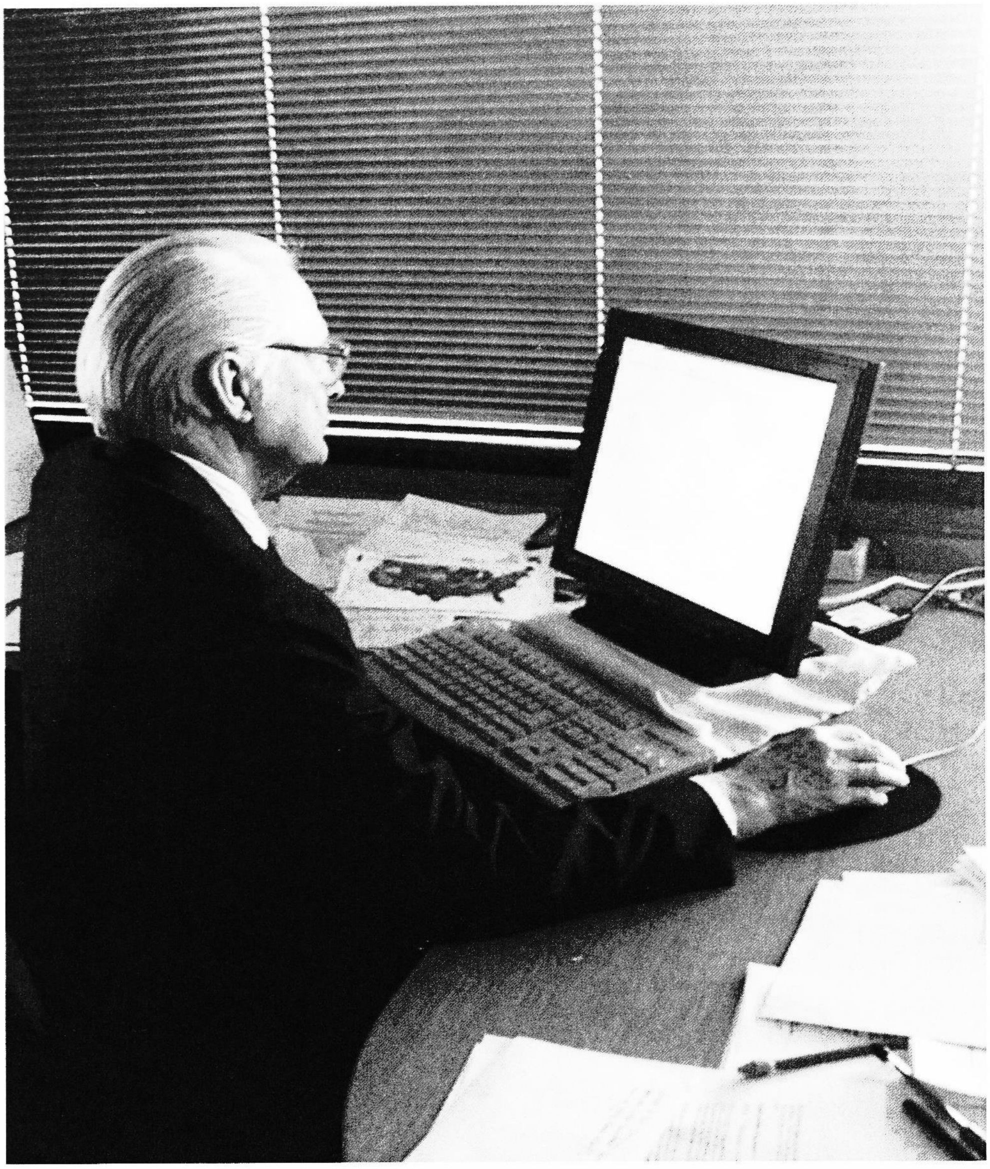
# HARRY R. GLAHN SYMPOSIUM

## The Evolution of Post-processing Methods in Weather Forecasting and Analysis



6 JANUARY 2015

PHOENIX, ARIZONA

## FOREWORD

This symposium honors Dr. Harry R. (Bob) Glahn's nearly six decades of pioneering work in the application of statistical methods to meteorology and statistical post-processing of information produced by operational numerical weather prediction (NWP) models. Statistical post-processing was in its infancy when he began his career in meteorology in the early 1960's. Since then he has been a leader in translating numerical model output into forecasts of sensible weather used in the suite of National Weather Service products and services serving the American public and service sectors, and providing critical guidance for NWS forecasters.

Bob served as the director of the Techniques Development Laboratory (TDL) (now the Meteorological Development Laboratory, MDL) from 1976 through his retirement in 2012. He was the leader, visionary, and a hands-on developer of the NWS' Model Output Statistics (MOS) system. He also led and contributed to the development of many of the technologies that enable information to flow smoothly from the NWP models to the gridded point forecasts now accessible through the internet. These contributions include objective analysis techniques, decision theory, product dissemination, product display, and forecast verification. He provided guidance and leadership for the development of the National Digital Forecast Database (NDFD), and early versions of Interactive Forecast Preparation Systems (IFPS).

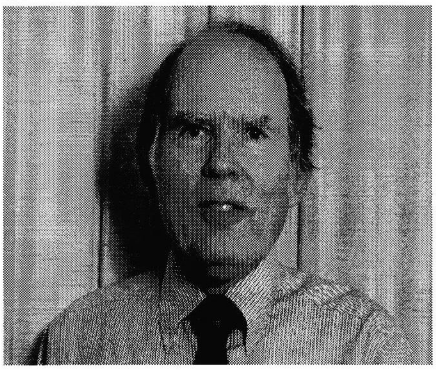
The breadth and impact of Bob's interests and contributions to our field are documented in the selected list of publications, which represents his work on probabilistic precipitation forecasts (1962), decision theory (1964), and statistical theory (1968). The first publication on MOS (Glahn and Lowry, 1972) has been sited nearly 800 times according to Google Scholar. His vision of forecast automation is preserved in the article on computer worded forecasts (1970), which was published 30 years before the widespread use of on-demand computer wording applied by NWS forecast offices today. His articles in the American Meteorological Society (AMS) journals include such diverse subjects as forecast verification (Glahn and Jorgensen, 1970), aviation weather forecasting (Glahn and Unger, 1986), gridded MOS (Glahn, et al., 2009), objective analysis (Glahn and Im, 2013), and even map projections (1990). His work ethic and dedication are legendary.

Bob Glahn is an active supporter of AMS activities and is a sponsor of a scholarship for young scientists interested in statistical applications within the atmospheric sciences. He continues to be active as a Scientist Emeritus of the NWS, a Fellow of the AMS, and a member of the AMS Committee on Probability and Statistics in the Atmospheric Sciences.

The Glahn Symposium includes representatives from the Government, private industry and academic institutions, both domestic and international. These scientists give a glimpse of the impacts of his many accomplishments and demonstrate the continuing innovations in the field of meteorology that his work has inspired.

Symposium Organizers

Barbara Brown
Chair, Probability and Statistics Committee
Director, Joint Numerical Testbed Program
Research Applications Laboratory, NCAR, Boulder CO



David Unger
NOAA/CPC, College Park, MD

## 1.1 Historic Impact of Harry R. (Bob) Glahn's Career on the National Weather Service

**Louis Uccellini**
*Director, National Weather Service, NOAA*
*Silver Spring, MD*

Dr. Harry R. (Bob) Glahn's remarkable career with NOAA's National Weather Service (NWS) has included seminal contributions both in leadership and scientific development. His career work was dedicated to studying and understanding the science of meteorology to improve the delivery of forecast services critical to the NWS mission. He revolutionized weather forecasting through the introduction and continual development of statistical post-processing of operational numerical models, known as Model Output Statistics (MOS). MOS enables direct forecasting of weather elements derived from the numerical models, and paved the way for a deeper understanding of the means for maximizing numerical predictive skill. As a measure of Bob's perseverance, and in the face of fierce opposition from forecasters and modelers, it took nearly 30 years for MOS to be accepted as a critical element in the overall forecast process. Bob's efforts were a major reason for the success in applying statistical post-processing to extract the non-biased information from numerical models required to make forecasts of specific weather elements applicable to general, aviation, marine, winter, severe weather and other forecast applications. Beyond his scientific contributions, Bob has influenced the future of the NWS through his continued leadership in student programs within the NWS and through the National Weather Association, providing opportunities for countless students who now work throughout the NWS. He has also dedicated himself to the study of the history of Signal Corp, the Weather Bureau, and the National Weather Service. His efforts to document this part of American History are an important element in our understanding of how weather forecasts and services have evolved over the past 140 years. This talk will cover these highlights of Bob's career, emphasizing his contributions towards applying meteorological science to improve enhanced services that today save lives and protect property across this country and around the world.

## 1.2 The Early Years – Statistical Interpretation Systems, Verification, and Computer-Worded Forecasts

**J. Paul Dallavalle**
*Supervisory Meteorologist (Ret.)*
*Meteorological Development Laboratory*
*National Weather Service, NOAA*

The 1960's and 1970's were a time of great change in meteorology. As knowledge of the atmosphere increased and observing systems improved, greater computer power made the possibility of accurate objective weather forecasting a reality. Simple dynamical weather prediction models like the barotropic were replaced by baroclinic models with sophisticated treatment of physical and thermodynamic processes. In the National Weather Service (NWS), a group of dedicated meteorologists led efforts to make weather forecasting an accurate, reliable service. The National Meteorological Center or NMC (later reorganized as the National Centers for Environmental Prediction) was responsible for the development and implementation of dynamical weather prediction models. A single model run, however, provided little information about the forecast uncertainty. While the model might predict measurable precipitation, the human forecaster had no indication of the confidence of that forecast. In addition, the early baroclinic models contained only rudimentary physics describing planetary boundary layer processes. Forecasts of air temperature or dew point at the observation shelter height were either unavailable or very inaccurate. Human forecasters subjectively interpreted the model forecasts, but an objective interpretation of model output seemed essential.

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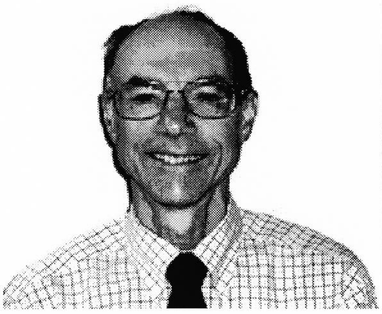

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In 1964, the Techniques Development Laboratory or TDL (later reorganized as the Meteorological Development Laboratory) was created. TDL's mission was to develop techniques that generated from the dynamical models objective guidance useful to NWS forecasters. Two scientists in TDL were primarily responsible for bringing statistical methods of interpreting model output to the NWS. Bill Klein was the Director of TDL from 1964 until 1976. Bob Glahn, with TDL from its inception, became Director of TDL in 1976 and served in that capacity until 2012. Reviewing TDL's first 25 years, Bob wrote: "The age of computers freed researchers from depending for development and implementation upon tedious manual calculations .... With a large mainframe computer at NMC ..., researchers could now think not only about multiple regression with many variables and large data samples for development, but also about distributing the results of such research to the field organization on a scheduled basis."

Many of the statistical techniques that Bob Glahn imported for testing at TDL were developed during the 1950's and early 1960's at the Traveler's Research Corporation. Various approaches were tried at TDL and found wanting for reasons of accuracy or complexity. Requirements for specific guidance influenced decisions. If a probabilistic product such as the probability of measurable precipitation was needed, logistic analysis could produce the requisite statistical relationships. If a categorical forecast like cloud cover was required, discriminant analysis could be used. For prediction of a continuous variable like temperature, multiple linear regression was appropriate. After experimentation, TDL chose multiple linear regression with numerous enhancements as a basis for a statistical interpretation system. The common approach, however, of collecting a small sample of data, punching the data on computer cards, and then writing software to analyze the data was both inefficient and error-prone. Bob Glahn ensured that digital data bases were established and quality-controlled, software was written in a systematic and documented fashion, and guidance products were developed and improved within a for-mal statistical analysis framework.

A second decision was critical in the early history of Bob Glahn. Two approaches were possible in the objective interpretation of model output. In the "perfect prog" meth-od, specification equations that related a meteorological variable like maximum temperature to observed or analyzed atmospheric conditions like upper-air heights or temperatures were developed. These equations were then applied to forecast output from a dynamical model. In the second approach, equations that related a meteorological variable to predicted variables from a dynamical model were developed. These equations were then applied to forecast output from the same or nearly the same dynamical model. Extensive testing showed that this latter approach, eventually known as Model Output Statistics or MOS, was superior to the perfect prog method. Eventually, an extensive suite of MOS guidance products was implemented.

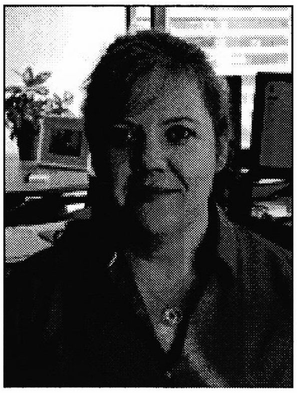
The changes to the forecast process created by implementation of dynamical models and MOS posed an existential threat to the human forecaster. If TDL could pro-duce statistical forecasts of weather elements based on the dynamical models, did the human add value to the final product? Could the NWS issue a public or aviation forecast based solely on statistical interpretation of the models? Bob Glahn considered these issues as early as the late 1960's. Under his leadership, TDL developed early versions of computer-worded forecasts and supported a verification system that collected local NWS public and aviation weather forecasts. Verifications showed the skill of the local forecasts improved with improvement in the dynamical models and MOS. Moreover, the local forecaster added value, particularly at the shorter-range projections.

Bob Glahn devoted over 50 years to public service. While this is extraordinary in terms of longevity, consideration of the obstacles faced by Bob reveals the magnitude of the achievement. Particularly during the early years of MOS, computer resources were scarce. Development was slow, and implementation of new products faced substantial hurdles. Major scientific differences about the direction of weather forecasting existed among the dynamical modelers, the statistical developers, and the forecasters. New statistical guidance products were often greeted with skepticism. In this environment, a leader needed vision, persistence, discipline, and organizational skills to succeed.

In this talk, we consider some of the events important in the history of Bob Glahn and the development of MOS. We focus on the years between 1968 when the first MOS product was implemented and 1988 when development of MOS guidance based on the Nested Grid Model was begun. We look at the replacement of perfect prog by MOS and the subsequent implementation of MOS guidance products. Consideration of the computer-worded forecast, a short-range update scheme known as LAMP, and some of the results of the national forecast verification system show that today's NWS forecast process had its roots in decisions made nearly 4 decades ago.

## 1.3 An Overview of the Model Output Statistics System

**Kathryn K. Gilbert,**
**Mark S. Antolik, Scott D. Scallion, Phillip E. Shafer,**
**Judy E. Ghirardelli, Yun Fan, Geoffrey A. Wagner**
*Meteorological Development Laboratory*
*National Weather Service, NOAA*
*Silver Spring, MD*

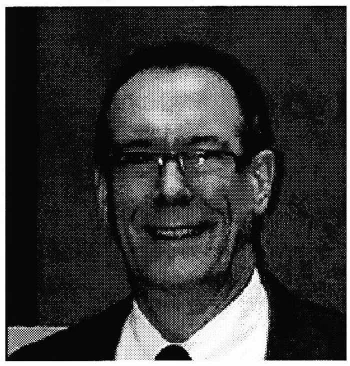


Model Output Statistics (MOS) forecast guidance has been provided to National Weather Service (NWS) forecasters and private entities for over four decades. MOS provides objective interpretation of numerical weather prediction models by relating observed weather elements to model predictors via a statistical approach. What began as the first operational application in 1969 as a three-element PE model-based message for 79 locations, has grown into a world class system commensurate with the size and scope of modern numerical weather prediction models. We now produce MOS guidance for more than 11,000 sites across the U.S. and its territories, and grids as fine as 2.5 km resolution. This guidance requires 7 hours a day of run time on the NWS production supercomputer, 150,132 lines of executable code, and 3.7 million unique statistical equations. Challenged to maintain a skillful MOS system in the face of frequent NWP model updates, today's efforts are focused on innovative approaches to respond to model changes, adapting our processing to new computing and IT environments, and responding to evolving weather services.

This talk will describe the current NWS MOS system: from data collection, through development of statistical forecast relationships, to product generation and dissemination to our users. Examples of MDL's MOS and related statistical guidance products will be shown, including our most recent efforts on the development of high resolution guidance on grids and our contribution to the National Blend of Global Models project. Downstream dependent or derived products add additional value to the MOS system and tailor products for specific customers. Examples of the Localized Aviation MOS Product, one such derived system, will also be shown. Today's NWS MOS system makes interpretive statistical weather forecasts accessible to a wide and diverse group of users: from government and military meteorologists to students, public health sector researchers, private sector forecasters in the energy and airline industries, broadcasters, and weather hobbyists and enthusiasts.

## 2.1 Ensemble Forecast Systems and MOS

**Matthew R. Peroutka**
*Meteorological Development Laboratory*
*Weather Service, NOAA*
*Silver Spring, MD*



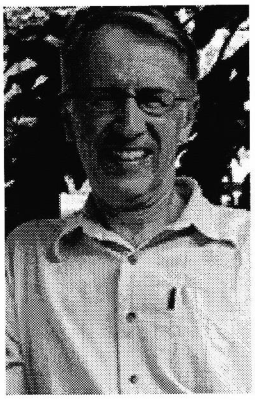
In the early 1990s, Model Output Statistics (MOS) was well accepted throughout the weather enterprise of the United States (US). That is when the National Centers for Environmental Prediction (NCEP; then named the National Meteorological Center [NMC]) implemented their first Ensemble Forecast System (EFS). Even then, MOS forecasts had been part of the operational mainstream for almost 30 years. As MOS and EFS both evolved, there were many calls for an "ensemble MOS" product. The earliest and simplest technique applied MOS equations that were developed with a single deterministic model to the various members of the EFS.

Developing a reliable and accurate ensemble MOS product, however, proved to be theoretically challenging, computationally intensive, and data intensive. In 2006, Bob Glahn formed a team within MDL to develop the product we would eventually name Ensemble Kernel Density MOS (EKDMOS). The team quickly learned that they faced twin challenges--the creation of accurate and reliable probabilistic forecasts and the development of appropriate forecast verification techniques.

This talk will review the workings of EKDMOS, its predecessor, enhancements that have been developed over the years, and the evolution of the EKDMOS products themselves. This talk will also show how the EKDMOS techniques are contributing to the NWS's Model Blender project.

## 2.2 Statistical Interpretation of Model Output Using MOS – A Canadian Perspective

**Laurence J. Wilson**
*Environment Canada, Emeritus*
*Dorval, Quebec, Canada*



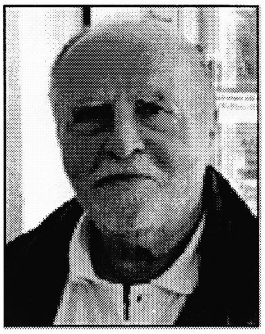
Model Output Statistics (MOS) is one of those rare ideas that is simple and yet incredibly effective and beneficial to operational forecasting. As an essential link between a model's version of the weather and actual observed conditions, MOS has rightly endured for more than 40 years and still is widely used for operational forecast guidance. In Canada, we learned about MOS from Dr. Glahn and Dr. Klein, and began to build a MOS system of our own in the early 1980s. Our first MOS product became operational in 1986, not for temperature, but for wind. By 2000, we had implemented the first version of the operational updateable MOS system that still runs today (UMOS).

MOS is based on the idea that model output can be corrected using (usually) fairly simple statistical methods. It has traditionally been focused on the statistical adaptation of the output of deterministic models. However, strictly speaking, all that is required for MOS is that model output be built into the statistical predictive equations; one is free to use any statistical methodology one likes. Furthermore, the output can be expressed as a deterministic forecast or as a probability. In the US and Canada (since 1982) MOS probability forecasts have been used as guidance for public probability forecasts long before ensemble-based estimates of probabilities became available.

This presentation will be in three parts: First, a brief history of MOS-related developments in Canada will be presented, followed by some examples of recent MOS applications. Then, finally, the question of whether MOS methods should change in future will be addressed.

## 2.3 Statistical Interpretation in Germany - the Last 50 Years

**Klaus Knüpffer* and Konrad Balzer****
** Meteo Service weather research GmbH, Berlin, Germany*
*** Deutscher Wetterdienst (Ret.)*
*Potsdam, Germany*

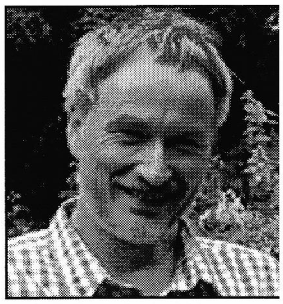


Dr. Konrad Balzer

This presentation wants to highlight the developments of statistical post-processing techniques in Germany and the impact of the 'so-far-away star' Bob Glahn who came much closer after the German unification.

The main developments in statistical post-processing techniques and verification in former East Germany are connected with the work and philosophy of K. Balzer - the nearer star of K. Knüpffer. He designed and improved the Perfect Prog system AFREG (analogue cases and regression) in the 1960s and 70s in parallel to the work in Sweden (Lönnqvist), and with further motivation by the work of TDL (Bill Klein). During the 1970s the breakthrough of MOS in the United States, documented by the pioneering work of Bob Glahn and others at TDL and the worldwide efforts led to the 'First WMO Symposium on statistical interpretation of broad scale NWP products into local weather elements' in Warsaw - with L. Bengtsson being spiritus rector.

The first German MOS system has been developed by R.v.Pander. It was operational during the 1980s at the German National Weather Service (Deutscher Wetterdienst, DWD) and based on the BKF model of DWD.



Dr. Klaus Knüpffer

During the 1980s the AFREG principle had been extended to a Multi-Model AFREG-Mix. It became evident that for certain elements such as wind speed, statistical forecasts could on the average not be improved any longer by the forecaster. Klaus Knüpffer, inspired by all these successes but lacking of access to sufficient computer capacity, made plans how an ideal weather forecasting system should look like in an ideal world (with unlimited computing power).

After the German unification K. Balzer implemented both AFREG-Mix and his comprehensive national verification system - inspired by the work of A. Murphy - at DWD.

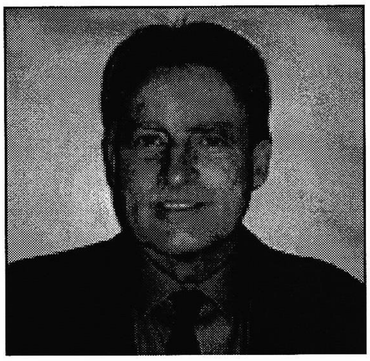
K. Knüpffer used the first opportunity to visit at TDL and experienced Bob's overwhelming hospitality in summer 1990. Inspired by both the success of his first MOS system - developed for the private Dutch company Meteo Consult Wageningen (now: Meteo Group) - and the idea of TDL, he made a proposal to append a 'European Centre for Statistical Post-Processing' to ECMWF - in vain, though. Instead, in 1994, he founded together with his Dutch partner Diederik Haalman the private company Meteo Service which is specialized in all aspects of MOS. It provides MOS services worldwide, based on the GFS model (and others in near future), for any interested customer - one of them being DWD. K. Balzer verified these MOS forecasts for one year before they were provided as guidance to the forecasters. This verification was unique in the sense that it provided information about the performance of the human forecasters as compared to a MOS guidance that they did not know when making these forecasts (usually the forecaster knows the guidance before). It revealed the superiority of MOS over the then operational Kalman-Bucy Filtering and also a significant advantage of MOS over the man-made forecasts. In our century, weather forecasting competitions are an efficient tool not just to play the weather forecasting game every weekend but also to compare and analyze the performance of different numerical models and different MOS algorithms. Results will be presented.

Applications of MOS extended from standard weather element forecasts to aviation weather forecasts, water level forecasts, as well as wind and solar energy forecasts. Whenever there is a direct numerical model output (DMO) for any observed element, we achieve a reduction of error variance of MOS of about 50% as compared to such a DMO. This turned out to be an almost constant value during the last 20 years. The benefit of using MOS at observing stations has been extended to the area by orography-dependent coefficient interpolation. This way NWP information in low spatial density (e.g. 1 deg Lat/Lon) can be transformed into site-specific weather forecast of any desired spatial density (e.g. a 1-km grid) with minimum loss of MOS forecast quality.

Bob once asked how a three-man company can do all this MOS stuff. A comparison (similarities and differences) of the approaches of TDL and Meteo Service shall provide some answer.

## 2.4 Adaptation of Model Output Statistics to Tropical Cyclone Forecasting

**Mark DeMaria**
*National Hurricane Center*
*National Weather Service, NOAA*
*Miami, Florida*

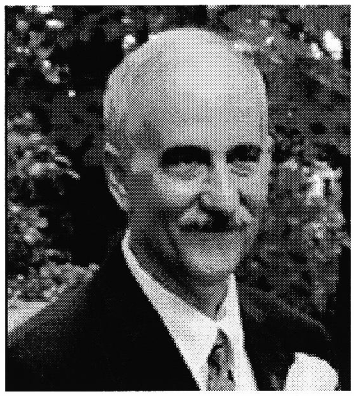


Bob Glahn was instrumental in the development of Model Output Statistics (MOS), which have provided valuable forecast information for more than half a century. MOS utilizes statistical methods to relate parameters that are well represented by numerical weather prediction models to forecast variables that are not well represented. For example, due to the complexity of land surface properties and other local effects, the direct prediction of surface temperatures may have limited accuracy at some locations. However, the low level thickness and other parameters that affect the surface are better predicted, and can be used as input to MOS to provide a more accurate surface temperature forecast. MOS techniques have also been applied to tropical cyclone forecasts since the late 1950s. The early techniques concentrated on both track and intensity, but the emphasis in the 1960s through 1980s was on track. The direct prediction of track by dynamical models became much more accurate in the 1990s so statistical track forecast techniques were no longer needed. Direct prediction of intensity was much more problematic and a number of statistical intensity methods have been utilized since the early 1990s. More recently, statistical post processing methods for TC tracks and intensity have regained favor in the context of providing optimal combinations of ensemble forecasts. The history of statistical tropical cyclone forecast methods is briefly reviewed, current methods are summarized and a future outlook is presented.

## 3.1 The Advent of Operational Digital Forecasts

**David P. Ruth**

*Meteorological Development Laboratory*
*National Weather Service, NOAA*
*Silver Spring, Maryland*



In the span of Bob Glahn's career, we have witnessed an increasing reliance by operational meteorologists on computer technology to complete tasks that were formerly infeasible or accomplished by manual methods. This transition is marked by 3 major advances, none immediately recognized as such, and each dependent on the success of the prior. The first advance came in the field of numerical weather prediction. Although not embraced by operational forecasters at the start, a thorough review of numerical model output is an indispensable step in preparing a forecast today.

A second major advance came with the statistical interpretation of numerical model output by employing techniques such as perfect prog and Model Output Statistics (MOS). Resisted by field forecasters when introduced, statistical forecasts are also now part of the routine process. In fact, MOS guidance has become an accepted benchmark by which human forecasts are judged.

The third major advance came with the nationwide implementation of the Interactive Forecast Preparation System (IFPS) at National Weather Service (NWS) Weather Forecast Offices (WFO). Instead of manually typing an array of lengthy text products tailored for specific user communities, forecasters rely on graphical forecast editing techniques to prepare detailed forecasts of weather elements in a common digital database 7 days into the future on fine-resolution grids. From this database, IFPS software automatically composes and formats the legacy text suite of NWS products, and many new products as well. More importantly, the high-resolution forecast itself is now provided in digital forms that enable users and partners to easily integrate operational NWS forecasts into their own decision support systems.

This presentation will highlight Bob Glahn's foresight and his key contributions to the implementation of IFPS and the National Digital Forecast Database (NDFD). It will cover the development of computer worded forecasts, interactive forecast techniques to manipulate digital forecast data, and the assembly of local digital forecasts into a national mosaic. The wide success of NDFD in providing decision support services will be described.

## 3.2 NWS Digital Gridded Services for a Weather-Ready Nation

**Christopher E. Strager**
*Office of Climate, Water and Weather Services*
*National Weather Service, NOAA*
*Silver Spring, Maryland*

NOAA has been committed to the mission of reducing loss of life, property, and the disruption from high impact weather and water-related events since its inception. However, in recent years the societal impacts resulting from well forecast extreme events has shifted the attention toward better decision making by communities, businesses, and the public. To this end, NOAA is committed to building a Weather-Ready Nation where society is prepared for and responds to these events. The Weather-Ready Nation (WRN) strategic priority is about building community resilience in the face of increasing vulnerability to extreme weather. NOAA recognizes it is essential to work collaboratively with external stakeholders within all levels of government, industry, nonprofits, and academia.

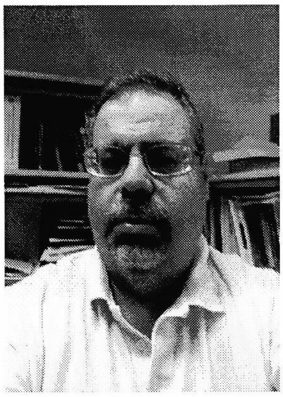
NOAA's contribution to building a Weather-Ready Nation focuses on improvements in the following areas:

- Communicating preparedness messages to user groups and the general public in a consistent, unified manner;
- Providing Impact-Based Decision Support Services (IDSS) to NOAA core partners during high impact events;
- Performing both physical science and social science research and transitioning innovative technologies into operations;
- Delivering lifesaving forecast and warning information to the public via multiple pathways (e.g., Wireless Emergency Alerts, use of social media);
- Enhancing pre-existing NOAA partnerships and establishing new partnerships across all sectors of society.

Digital gridded services incorporate (IDSS), Science and Technology, and dissemination contributions from within the WRN initiative. NWS plans for digital gridded services take the foundational contributions from Bob Glahn and incorporate them to provide high resolution, deterministic and ensemble-based probabilistic gridded forecasts that will eventually extend out to day 10 and beyond.

## 3.3 Making Sensible Weather from NWP Output: An Operational Perspective of MOS

**Jeff S. Waldstreicher**
*Eastern Region Headquarters*
*National Weather Service, NOAA*
*Bohemia, NY*



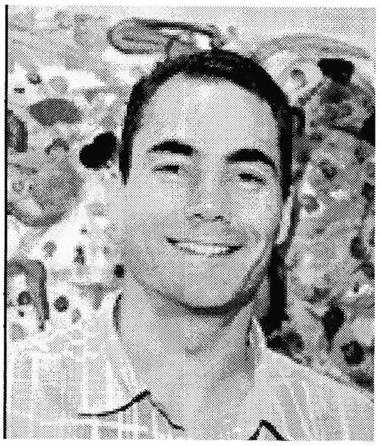
For more than four decades model output statistics (MOS) have been an invaluable tool for forecasters. This talk will highlight how, through statistical methods, MOS objective guidance has provided operational meteorologists with a bridge between raw NWP output and the production of forecasts of sensible weather elements for a wide range of applications. In addition to basic surface variables such as temperature, dew point and winds, MOS guidance has been a vital source for forecasters' efforts in preparing public and aviation forecasts of sky conditions and precipitation occurrence, including precipitation type and visibilities. The ability to account for much of the systematic biases within operational modeling systems has been a valued strength of the MOS approach. The quality of MOS forecasts has long been sufficiently high to provide a historical baseline for comparison to operational forecasts. Improvements over MOS guidance have become a standard measure for assessing the quality of human-produced forecasts.

MOS has also provided operational forecasters with objective probabilistic forecast guidance for many sensible weather elements. The robust statistical calibration of the MOS system has also provided forecasters with a hands-on training tool to better understand and formulate reliable probabilistic forecast information.

Originally derived for specific locations, MOS has expanded in recent years to provide gridded objective guidance to support new digital forecast initiatives. Early efforts to utilize MOS forecasts to generate computer worded forecasts also provided a foundation for an evolution of the forecast process to a modernized database of weather information.

## 3.4 Statistical Post Processing for US Navy Ship Routing

**Jim Hansen[1],**
**Jim Peak1, Liz Satterfield[1], Jay Morford[2], Justin McLay[1], Chad Hutchins[1], Will Henry[3], Rich Bankart[1], Morgan Gorris**
*[1]Naval Research Laboratory, Monterey, California*
*[2]Computer Systems Corporation, Monterey, California*
*[3]SAIC, Monterey, California*
*[4]University of Michigan, Ann Arbor, MI*



It has been demonstrated that an operational system to route US Navy ships could save the Department of Defense on the order of $150M/ in fuel costs. The Naval Research Laboratory Marine Meteorology Division implementing a routing guidance system that optimizes fuel subject to the constraint of ship safety. Experiments have shown that a) routes are most sensitive to forecasts of waves and winds, b) ensemble forecasts adds value, and c) statistical post processing of winds and waves adds value. NRL has developed and implemented a Lagrangian-based post-processing system winds and waves that has proven to be superior to Eulerian-based methods ocean conditions. NRL is also exploring the relative merits of using post-processed waves directly vice using the waves produced by forcing the operational wave model with post-processed winds. Results and future directions will be discussed.

## 3.5 Localized Aviation MOS Program (LAMP): A Statistical Post-processing System for the Past, Present, and Future

**Judy E. Ghirardelli**
*Meteorological Development Laboratory*
*National Weather Service, NOAA*
*Silver Spring, Maryland*

Nearly 35 years ago, Bob Glahn first documented the National Weather Service's (NWS) efforts in the Techniques (now Meteorological) Development Laboratory to develop a "LAMP" system to produce statistically post-processed short-range forecast guidance. While the definition of the LAMP acronym has changed as the system evolved, the goal of LAMP, to provide good quality objective forecast guidance for aviation in the short-range period, has remained the same.

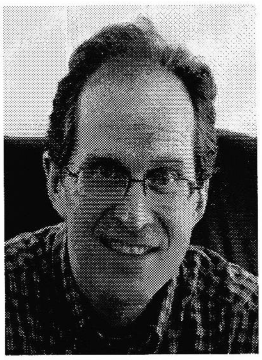
Today LAMP stands for the Localized Aviation MOS Program, and LAMP guidance is centrally created every hour at the NWS National Centers for Environmental Prediction. LAMP guidance is produced for 1692 stations in the contiguous United States (CONUS), Alaska, Hawaii, and Puerto Rico, and on the National Digital Forecast Database 2.5-km CONUS grid. It provides forecast values and probabilities for the next 25 hours.

The guidance is available at NWS Weather Forecast Offices, across the Satellite Broadcast Network and NOAAPort, in the National Digital Guidance Database, and on the internet, and is used by NWS and military forecasters, private meteorologists, the Federal Aviation Administration, commercial airlines, energy companies, and private citizens.

This presentation will provide an overview of the LAMP system of the past, where the system is today, the present challenges for statistical post-processing for aviation guidance, and where we expect LAMP to be in the future as we meet those challenges.

## 4.1 New Directions in Statistical Post-Processing

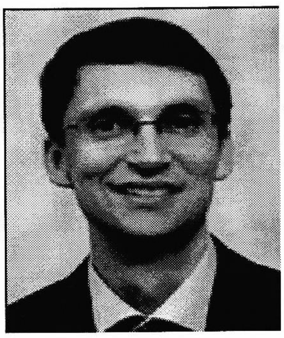
**Thomas M. Hamill**
*Physical Sciences Division, Earth System Research Laboratory*
*Oceanic and Atmospheric Research, NOAA*
*Boulder, Colorado*



Statistical post-processing involves using past forecast information and associated observations/analyses to adjust for deficiencies in the current forecast. This talk will discuss some very recent developments in statistical post-processing, will review some of the more substantial remaining challenges, and will suggest some fruitful paths for future inquiry. Recent developments will include "ensemble copula coupling" as a way of preserving space-time covariance information in post-processed guidance and novel parametric methods of post-processing. Substantial remaining challenges include how to provide high-quality post-processed guidance with a limited training sample size of past forecasts and observations and incorporating information from ensembles in the post-processing. New directions may touch upon ideas such as the use of wavelets decompositions in statistical post-processing.

## 4.2 Recent Trends in Forecasters' Use of Post-processed Guidance

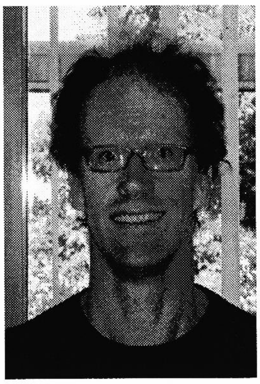
**David R. Novak**
*Weather Prediction Center*
*National Weather Service, NOAA*
*College Park, Maryland*



With the introduction and subsequent improvement of Model Output Statistics, forecasters have increasingly embraced post-processed model guidance in the forecast process. Recently, the changing nature of extreme events and evolving user requirements are demanding innovations to traditional post-processed guidance. At the Weather Prediction Center, forecasters interpret and apply a wide variety of post-processed guidance to serve as a center of excellence in quantitative precipitation forecasting, medium range forecasting, and winter weather forecasting. Based on WPC's experience, this talk will explore recent trends in forecasters' use of post-processed guidance, including traditional MOS, blends of multiple models, best-worse case scenarios, reforecasts, and neighborhood approaches. Further, innovative visualization of post-processed fields that allow forecasters to quickly assess guidance and focus on high-impact events will be highlighted. Such changes are facilitating the evolution of the role of the forecaster to higher-order decision making and decision support activities.

## 4.3 Consensus Weather Forecasting: The Next Generation of Statistical Model Post-Processing

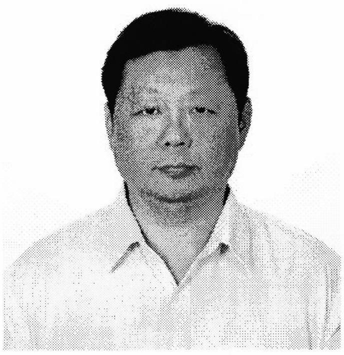
**William Myers**
*Global Weather Corporation*
*Boulder, Colorado*



In the past 15 years, operational weather forecasting advancements in the post-processing of numerical weather models have significantly improved the weather forecasts provided to the public. The development of consensus forecasting techniques has probably led to the largest reduction in forecast errors since the advent of Model Output Statistics (MOS) in the 1960s. The Dynamic Integrated ForeCast System (DICast), developed in the late 1990s at the National Center for Atmospheric Research (NCAR), is a completely automated consensus forecast system that was modeled on the human forecast process. It considers multiple forecast inputs and continually compares its forecasts to observations in a machine learning approach that generates objective forecasts that outperform its ingredient forecasts, including NWS and ECMWF products. DICast now drives the forecast engines of several of the largest weather forecast providers in the United States and, to an increasing degree, internationally.

## 4.4 Taiwan CWB MOS System

**Jonq-gong Chern**
*Central Weather Bureau*
*Taipei, Taiwan*



The CWB MOS system was established at 1997, and officially operated since 2000 (MOS 2000) till date. However, the MOS guidance performance is restricted by the NWP forecast potential, which is dominated by the extraordinarily geographic location and topographic distribution of Taiwan area.

Geographically Taiwan is located in the flank of eastern Asia continent and bordering North-western Pacific ocean-basin; climatically it locates in the Eastern subtropical Monsoon region. Since the special seasonality for 2-month's period, CWB MOS System is designed to base on each month's MOS equations and its model training period is 2-month data in a year, which includes previous and following half-month to count for the seasonal shifting.

Inside Taiwan area, around 385km from north to south and 143km for the maximum width in the west-east direction, the steep central mountain penetrates through north to south, and the highest mountain peak, Yushan, is 3,952 meters. Because of the complex topography, the river flows are rapid and turbulent during raining seasons. Serious disaster, flash flood and mud-slide etc., becomes as the inevitable result when there is a severe storm occurred or Typhoon invaded. Due to the complex characters of seasonality and topography, the CWB MOS equation is generated by each station individually, not based on climatic regional station group.

Under both monitoring and observing purposes, a dense CWB observatory network is built for more than 20-year. There are around 500 observing stations and 4 meteorological radars, and also meteorological satellite operate routinely. The observatory net almost fully covers Taiwan area and provides sufficient records to develop MOS System.

The Taiwan CWB MOS System provides both regional NWP model for short range and global NWP model for medium range forecast guidance. Although the regional NWP model simulation can provide fine grid information to generate MOS equation, both regional and global NWP model show that the topographic affect obviously reduces the MOS model's explanation potential, from coastal to mountain regions, seriously. For the temperature related MOS guidance, it only shows slight bias difference from coastal to mountain region. But for precipitation related guidance, it might provide the wrong location to precipitate, since the NWP convergence simulated failure. Under this circumstance, the CWB MOS wind direction guidance is not recommended to refer for forecaster, because NWP forecast wind direction in mountain area might be totally reversed with station's observation.

To gain more capability of MOS model explanation, the NWP model persistence is utilized to develop the CWB MOS model by including certain numbers of neighboring leading and after projections in the target projection MOS equation. It does increase the forecast equation's explanation, but also it might take a higher risk of forecast stability for the MOS equation. The CWB MOS model's maintenance is issued by the forecast performance of the same NWP model's paralleling PP(Perfect Prog.) forecast better than the MOS model's. There are two options provided, one is to update dataset and adjust predictors' weighting, the other is to regenerate the MOS model.

Before 2009, the CWB MOS System is focus on developing CWB's regional(LFS and NFS) and global(GFS) NWP models. We experienced to develope Tmax, Tmin, PoP, categorical cloud amount, wind speed, wind direction and categorical QPF station guidance. Since 2009, under the FIFOW(Fine Information of Formosa Weather) project, both station and gridded(2.5km*2.5km) MOS guidance were created and more NWP models' guidance were included. For the regional (NFS and WRF) models, the MOS operations are performed on 00Z, 06Z, 12Z and 18Z every day, and MOS products are provided by every 3-hour interval till 84-hour leading forecast projection for each initial operation. The medium range MOS guidance are based on NCEP, EC and JMA GFS models, 2 initial(00Z and 12Z) operations per day, and products are provided by every 12-hour interval till 192 leading forecast hours for each initial operation. The CWB FIFOW MOS System works as the forecast foundation to allow forecaster providing more meticulous weather forecast services of weather element's evolution from major cities to local villages within Taiwan area.

The future challenges of the CWB FIFOW MOS System will focus on increasing the forecast accuracy and also providing probabilistic products. Developing ensemble MOS scheme will be the most important fundamental task. Then base on the ensemble scheme, the application of multi-model ensemble MOS will be utilized to benefit the CWB forecast services.

Since recent NWP model's improvement and the needs from social or business activities, we also begin to study the potential of MOS works on the 2nd week to one month forecast development.

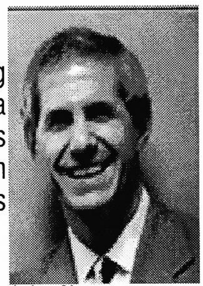
Taiwan area experienced severe weather disaster frequently. Although it may be warming by the MOS probabilistic guidance, however it is difficult to predict its occurrence, and not to mention to provide the quantitative intensity. In according to the regional CWB-NFS MOS categorical QPF developing experiences, when the MOS model successfully decide the correct rainfall category, then employ the indicated categorical rainfall interval's historical data setup the QPF MOS equation directly, it gave higher potential to approach the observed quantitative precipitation. Since Taiwan's topographic affect cause the regional NWP model provides limited information to make a right choose for MOS QPF category. We are planning an online operating process, the first procedure is to utilize the ANALOG methods to analyze and select the similar cases from the previous reanalysis global data and historical Taiwan's observed data, which in according with the most recent local and global observed records. The purpose is to select the cases in the same cluster, as to narrow the categorical interval. The second procedure is to form the quantitative MOS equations directly by the assigned reforecast NWP data with those selected cases in the first procedure, and then generate the MOS forecast guidance. Also those selected similar initial cases may suggest the possible following weather evolution in the probabilistic sense.

## 4.5 Forecasting Regional Chance of Occurrence through Aggregation of MOS PoPs

**George S. Young, Sreece D. Goldberger,**
**Johannes Verlinde, Chris Hanlon, and Jon M. Nese**
*Meteorology Department*
*The Pennsylvania State University*
*State College, Pennsylvania*


George Young

Regional sets of point probabilities, e.g. MOS PoP forecasts, can be used to forecast both the expected areal coverage and the regional chance of occurrence. The former is just a data quality check given the statistical equivalence of the spatial average of point probabilities and the expected value of areal coverage. The latter, however, is a new product with utility to those users whose actions depend upon the occurrence of the event anywhere within their region of operation. While the method is demonstrated here using MOS PoP forecasts, potential applications include any weather variable for which point probability forecasts are available operationally. The forecasting of thunderstorm chance of occurrence for fire weather planning is one such application.


John Nese

For this demonstration, MOS PoP forecasts are matched with the corresponding NCEP Stage IV precipitation analyses. Comparison of regional average PoP with fractional area coverage verifies their equivalence, but reveals a MOS station location bias to the drier lowlands in the intermountain West. Regional chance of occurrence is forecast via logistic regression with mean and standard deviation of the region's MOS PoP forecasts as predictors. Hindcast results show significant skill, but the regression equations vary by both season and location.

## 4.6. National Weather Service's Meteorological Development Laboratory – Where We are and Where We're Going

**Michael R. Farrar**
*Director, Meteorological Development Laboratory*
*National Weather Service, NOAA*
*Silver Spring, Maryland*

From 1976-2012, Dr. Harry "Bob" Glahn led the Meteorological Development Laboratory (MDL), formerly the Techniques Development Laboratory (TDL), in dedicated support of the operational forecasting mission of the National Weather Service. Over the years, MDL has provided ever-increasingly valuable tools and products that enable the forecasters to perform their mission to the Nation, directly attributable to Bob's vision and leadership. In addition, Dr. Glahn made mentoring the next generation of meteorologists and physical scientists a priority; as such, MDL has served as a breeding ground for dozens of students, many of which moved into permanent positions and then on to successful careers as forecasters and as leaders in the NWS.

In carrying on Dr. Glahn's legacy, MDL today continues to serve by providing key products and capabilities to support the NWS mission of protecting life and property. This presentation will take a brief look back at the first 50 years of MDL, providing a high-level summary of the Lab's accomplishments and capabilities, many of which were covered in greater detail by other preceding presentations. The presentation will then provide an overview of MDL's current activities, spotlighting recent accomplishments and improvements. It will then conclude with our vision for the future, to include both short-term plans for incremental improvements, as well as a strategic long-term look at how the Lab will advance to meet the evolving challenges faced by the NWS and its customers.

### Poster 444: Some aspects of the verification of weather forecasts for Melbourne, Australia

**Harvey Stern**, *University of Melbourne, Parkville, Vic., Australia; N. E. Davidson*

The authors have recently completed a piece of work exploring trends in the skill of weather prediction at lead times of 1 to 14 days for Melbourne, Australia. The system that was used to establish these trends (at longer lead times) was, in part, based upon an algorithm that statistically interpreted the GFS NWP model output to generate local weather forecasts. It was considered that it would be interesting to assess what might be achieved using the output of other global NWP models. Preliminary results are presented about what has been achieved using the ECMWF monthly control NWP model. The general public's first impression of the forecast weather is provided by the official précis of that forecast. Using an algorithm that interprets the words contained in the précis in terms of precipitation provides guidance on how successfully the précis provides useful information about precipitation amount and probability. Capability at predicting unusual weather events is of importance. Some statistics are presented on how effectively one can now predict weather that is somewhat different from climatological norms. Finally, the skill of the aforementioned system at predicting differences in temperatures recorded at the current Melbourne Central Business District (CBD) site, and those at a new observation site just outside the CBD, is discussed.

### Poster 446: Statistical Post-Processing of GEFS Ensemble Forecasts for Precipitation Accumulations

**Michael Scheuerer**, *NOAA, Boulder, CO; and T. M. Hamill and P. J. Pegion*

We present a post-processing method that generates full predictive probability distributions for precipitation accumulations by fitting shifted, left-censored gamma distributions to statistics of the raw ensemble forecasts. This distribution type is shown to be adequate for modeling the distribution of observed precipitation accumulations given the ensemble forecasts both in situations with good predictability (e.g. at short lead times) and decreased predictability (e.g. at longer lead times or during summer months). When the forecasts are only available on a coarser grid than the verifying observations, our approach can perform downscaling in addition to calibration.

The proposed method will be demonstrated with GEFS precipitation reforecasts over the conterminous United States and verified against an 1/8-degree climatology-calibrated precipitation analyses using common metrics (skill, reliability, and so forth). We also discuss the effect of training sample size on the calibration of the post-processed predictions and show how an intelligent pooling of training data across different grid points can partially compensate for a reduction of the length of the reforecast data set used for model fitting.

### Poster 447: Application and verification of ECMWF seasonal forecast for wind energy

**Mark Zagar,** *Vestas Wind Systems, A/S, Aarhus, Denmark; T. Maric, M. Qvist and L. Gulstad*

A good understanding of long-term annual energy production (AEP) is crucial when assessing the business case of investing in green energy like wind power. The art of wind-resource assessment has emerged into a scientific discipline on its own, which has advanced at high pace over the last decade. This has resulted in continuous improvement of the AEP accuracy and, therefore, increase in business case certainty.

Harvesting the full potential output of a wind farm or a portfolio of wind farms depends heavily on optimizing operation and management strategy. The necessary information for short-term planning (up to 14 days) is provided by standard weather and power forecasting services, and the long-term plans are based on climatology. However, the wind-power industry is lacking quality information on intermediate scales of the expected variability in seasonal and intra-annual variations and their geographical distribution. The seasonal power forecast presented here is designed to bridge this gap.

The seasonal power production forecast is based on the ECMWF seasonal weather forecast and the Vestas' high-resolution, mesoscale weather library. The seasonal weather forecast is enriched through a layer of statistical post-processing added to relate large-scale wind speed anomalies to mesoscale climatology. The resulting predicted energy production anomalies, thus, include mesoscale effects not captured by the global forecasting systems.

The turbine power output is non-linearly related to the wind speed, which has important implications for the wind power forecast. In theory, the wind power is proportional to the cube of wind speed. However, due to the nature of turbine design, this exponent is close to 3 only at low wind speeds, becomes smaller as the wind speed increases, and above 11-13 m/s the power output remains constant, called the rated power. The non-linear relationship between wind speed and the power output generally increases sensitivity of the forecasted power to the wind speed anomalies. On the other hand, in some cases and areas where turbines operate close to, or above the rated power, the sensitivity of power forecast is reduced. Thus, the seasonal power forecasting system requires good knowledge of the changes in frequency of events with sufficient wind speeds to have acceptable skill.

The scientific background for the Vestas seasonal power forecasting system is described and the relationship between predicted monthly wind speed anomalies and observed wind energy production are investigated for a number of operating wind farms in different climate zones. Current challenges will be discussed and some future research and development areas identified.

### Poster 448: Customized Verification of High-resolution WRF-ARW Forecasts using the Model Evaluation Tools (MET) Package

**James P. Cipriani**, *IBM Research, Yorktown Heights,, NY; L. A. Treinish and A. Praino*

Forecast verification is a key component of both research and operational weather modeling. Generating and understanding a wide range of skill scores over a forecast database can help to determine potential biases and outliers, allow for the fine-tuning of the model configuration, and build user confidence. For continuous variables (such as temperature, dew point, and wind speed), typical scores include mean absolute error (MAE), root mean squared error (RMSE), and mean error (ME, aka additive bias), which are based on direct (point-to-point) comparisons of forecast vs. observed values. For categorical variables (such as accumulated precipitation), scores can include critical success index (CSI, aka threat score), probability of detection (POD), and Accuracy (ACC), and are based on a contingency-table analysis (hits, misses, false alarms, and correct negatives). Given the strengths and weaknesses of each metric, it is often desirable (and necessary) to utilize multiple scores in order to assess the overall quality of the forecasts.

IBM has developed a high temporal and spatial resolution weather forecasting capability, known as Deep Thunder, which is customized for particular geographies and client requirements. Typical horizontal resolution is 1-2 km, with lead times out to 72 hours. Current deployments include the Detroit and New York metropolitan areas, southeast and northeast U.S., city of Rio de Janeiro, and country of Brunei. The validation is often performed according to client specifications and is based on comparisons against surface observations, which include both point (weather observing system) and gridded data.

The NCAR Developmental Testbed Center (DTC) has developed the Model Evaluation Tools (MET) verification package, which is highly-configurable and can operate on post-processed output from WRF-ARW (and can be applied to other model output as well). It includes standard scores for point-based (model grid to point), grid-point to grid-point, spatial, ensemble, and probabilistic verification.

To better validate the operational Deep Thunder forecasts, the METv4.0 package has been implemented and utilized for both point-based and grid-point to grid-point comparisons. We will discuss aspects of the verification process, data and customization, some results thus far (for specific geographies), challenges, and future work.

## Poster 449: Forty Years of NWS Forecasts: Past Performance and Future Advances

**Tabitha L. Huntemann**, *NOAA/National Weather Service, Silver Spring, MD; D. E. Rudack and D. P. Ruth*

The Meteorological Development Laboratory (MDL) of the National Weather Service (NWS) has issued model output statistics (MOS) guidance forecasts for nearly four decades. For many years, MOS guidance was generated for observing stations and formatted in text bulletins while official NWS forecasts for stations and zones were created by forecasters typing text. Today, the National Digital Forecast Database (NDFD) contains official NWS forecasts produced by forecasters at local Weather Forecast Offices (WFOs) and national centers on a fine-resolution grid. MDL also issues gridded MOS guidance in support of NDFD. Recently, MDL has applied the MOS approach to the European Centre for Medium-Range Weather Forecasts (ECMWF) model to generate additional station-based guidance.

The NWS and MDL routinely evaluate official forecasts at stations and compare the skill of the human forecast to the guidance for the same weather element. Improvements in NWS public weather forecasts and in statistically post-processed numerical weather prediction (NWP) can be traced by the verification of the weather element guidance.

In this paper, we examine the skill at stations of four decades of official NWS maximum temperature, minimum temperature, and 12-h probability of precipitation forecasts compared to MOS guidance for forecast periods out to approximately 60 hours in advance. The skill of the forecast and guidance has increased significantly since the late 1960s and early 1970s. We also investigate the performance of the last two years of NDFD, Global Forecast System-based MOS (GFS MOS), and ECMWF MOS forecasts for forecast periods out to seven days in advance.

# From farmer and country school teacher to NWS Scientist Emeritus

As a young man in 1946 who helped his father farm his land in Missouri, Dr. Harry R. (Bob) Glahn never anticipated that he would one day have such an amazing career with the NWS, much less become the agency's first Scientist Emeritus.

Glahn also could be considered a scientist extraordinaire, since he is recognized throughout the world for his work with applied statistics. His extraordinary and historic career with the NWS has spanned over 54 years. Glahn had such an impact on the way forecasters gather, analyze, and present meteorological information, that the NWS chose him for the new and distinguished honor of being its first Scientist Emeritus.

In 1947, he became a rural school teacher in Missouri, continuing until 1951. While teaching, he studied at Northeast Missouri State Teachers College, (now Truman State University) receiving his bachelor's degree in 1953; Glahn then joined the U.S. Air Force.

The Air Force sent him to Oklahoma A&M College to study meteorology and this led to him becoming a forecaster in the Air Force Alaskan Weather Center in Anchorage. Glahn liked meteorology so much that after the Air Force, he entered the Massachusetts Institute of Technology, where he received his Master of Science degree in 1958.

It was with his Master of Science degree in hand that Glahn headed to the U.S. Weather Bureau (the predecessor of the National Weather Service), starting an impressive career that would last more than five decades. Upon coming to the Washington D.C. area, he studied statistics at the American University, and then entered the Pennsylvania State University on a fellowship and earned his Ph.D. in meteorology with a minor in statistics in 1963.

When Glahn entered the NWS in 1958, the agency was starting to experiment with computer technology, and Numerical Weather Prediction. Forecasts from the models weren't very good at that point, but Glahn states, "It was obvious this was the way of the future. It was also obvious it would be a long time before "real weather" was forecast by the models, as they concentrated on the upper atmosphere. It was also obvious this was the place for statistics to play a role. The idea of Model Output Statistics (MOS) was quickly born."

To know how much the world has changed since 1958, it helps to look back: the federal minimum wage was $1.00; a new car sold for under $4,000; and filling the tank cost $0.25 a gallon. No one owned a personal computer.

In the 1960s, while working in the Office of Meteorological Research, Glahn developed and successfully shepherded the implementation of MOS, which is a technique used to objectively interpret numerical model output and produce site-specific guidance.

"MOS is a method of producing weather forecasts that uses advanced statistical techniques to improve the accuracy of forecasts generated by computer models," explained Glahn. "Especially, probabilistic prediction has always been one of my personal research interests."

Glahn's implementation of MOS was a major step in applying probability and statistics to create weather forecasts. MOS has helped forecasters produce high-quality weather forecasts up to seven days in advance. The MOS technique is used by almost every major national meteorological service in the world.

Glahn began his lastest position at the NWS in 1976 when he became Director of the NWS Techniques Development laboratory (now the Meteorological Development Laboratory). It was at TDL that he used his scientific expertise and leadership to continue to research, develop, and implement more efficient and effective scientific and forecasting services.

In the early 1990s, during the NWS modernization, Glahn sought to free forecasters from having to manually type hundreds of text forecasts. Instead, he envisioned forecasters using high-tech tools to analyze and probe complex and hazardous weather situations. Chief among these advancements in AWIPS (Advanced Weather Interactive Processing System) was the Interactive Forecast Preparation System, or IFPS, which allowed a transition from manpower intensive text products to more efficient, information-rich digital and graphical weather forecast products. Glahn, proficient in map projections, defined the grids in use by Weather Forecast Offices in AWIPS.

"A critical element of IFPS success is to have software that will compose information from the local database [grids] into text products," Glahn reported in a 2003 NWS Focus article. He explained further that NWS forecast offices "can use the baseline formatter for the zone product and a locally-developed formatter for the fire weather product, or vice-versa." Glahn was constantly looking for ways to take the NWS to the next frontier. He set in motion a nationwide team to develop the National Digital Forecast Database, or NDFD, in which the gridded forecasts produced at every NWS weather forecast office are forged into a single, national gridded forecast database. Early in his career, Glahn developed the first computer worded forecast in the world, which had a major impact on how forecast products are created. The computer production of text from the NDFD is now used throughout the NWS.

Thanks in large part to Glahn's diligence, the MOS and NDFD projects are not only examples of technological greatness, but are also great connectors that link NWS forecasters together to protect the lives of NWS customers and the American public at large.

Glahn has authored or co-authored more than 160 scientific papers on various topics. A Fellow of the American Meteorological Society, he has received several awards, including the AMS Cleveland Abbe Award, the NOAA Distinguished Career Award, and the Department of Commerce Silver and Gold Medal awards.

Glahn has a true sense of what it means to "pass it on." He established American Meteorology Society and National Weather Association scholarships, each providing $2,500 annually for students to study statistics as related to meteorology. He wants to give opportunities to learn probabilistic prediction to the next generations of meteorologists.

While many people might choose to go golfing or fishing after retirement, Glahn plans to return to the environment he's felt most comfortable in for the past five decades — volunteering for the NWS and continuing his interests in statistical meteorology.

NWS Acting Director Laura Furgione has said, "You aren't simply hired at the Weather Service–you are called."
"Actually, we are called for life," says Glahn. "Once weather gets in your blood, it is there to stay."
Furgione has praised Glahn for his long career and his contributions to both NWS and the field of meteorology. "When he first started working at the Weather Bureau in 1958, the meteorological world was a different place," said Furgione. "He has left his stamp on the world of meteorology and as the first Scientist Emeritus of the NWS, he once again broke new ground."

## *Nomination Letter*
## *Cleveland Abbe Award*

April 10, 2003
Awards Oversight Committee
American Meteorological Society
45 Beacon Street
Boston, MA 02108-3693

Dear Colleagues,

It is extremely rare that a single individual makes seminal contributions that open up a whole new area of applications having world-wide significance, and then provides leadership and direction in exploiting and extending that area throughout a decades long career. Yet that is what Dr. Harry R. (Bob) Glahn has accomplished with a unique blend of vision, focus, adaptability, and dedication in the development of objective, reliable, detailed, timely, automated weather analysis and forecast products. This accomplishment already has significantly improved the utility and value of meteorological information for all kinds of users, and has established the foundation for a major expansion and diversification of applications in the future. It is a privilege to support Dr. Glahn's nomination for the Cleveland Abbe Award in recognition of this lifetime achievement.

The recent introduction of a prototype National Digital Forecast Database in the National Weather Service represents the culmination of more than thirty years of innovation, planning and perseverance in the research and development of a complex array of interrelated techniques and systems. Dr. Glahn personally conceived many of the critical elements, and organized and led the overall effort. As early as 1970 he was publishing papers on computer-produced worded forecasts, portending the dramatic evolution made possible by the continuing explosion of computer and software capability. His pioneering work in applying modern statistical techniques to derive reliable and specific forecasts of critical weather variables from the hard-to-use and often erratic output of numerical-dynamical forecast models is widely recognized. The resulting Model Output Statistics (MOS) products and techniques have been adopted worldwide since their introduction in the 1970's. However, the breadth, depth, and continuity of his contributions are perhaps less widely appreciated.

Dr. Glahn entered meteorology as an Air Force Weather Officer in the 1950's like many illustrious colleagues. He joined the U.S. Weather Bureau in 1958 as a research meteorologist and rose through the ranks to section and branch leader, Deputy Director and in 1976 became Director of the Techniques Development Laboratory of the National Weather Service. During this period he recognized the large gap between the information that public and private sector users of weather information wanted and needed, and what the largely manual methods in use at the time could provide. He also foresaw that computer-based methods held great promise in bridging the gap, and began a systematic effort to make it happen.

The changes Dr. Glahn envisioned required not only great scientific and technical skill, but they also demanded fundamental cultural and institutional adjustments. Weather forecasters rightly take great pride in their ability to integrate vast and diverse types of information, including user needs, while rendering professional judgments. Early experience amply demonstrated that computer-based methods, especially NWP, were subject to serious and largely unpredictable errors. As automated MOS forecasts provided greater reliability and covered more relevant variables than NWP alone, they became competitive with manual forecasts. Some individuals projected the future irrelevance of human forecasts, while others decried a possible "cancer" where forecasters accepted the statistical forecasts rather than using their intellect to improve them.

Dr. Glahn was well aware of the growing controversy and took effective steps to address the issues. He emphasized the development of products to serve as "guidance" or assistance to manual forecasters, providing a starting point or comparison for manual methods. He also focused on tools to help the forecasters with details of data collection, organization, and access, and also in the actual preparation of products. The forecaster remained the ultimate authority. He also stressed the development of objective measures of the quality of forecasts, both automated and manual, so that progress in both could be tracked and fostered. Dr. Glahn was a conspicuous leader in the development of workable evaluation and verification techniques from at least the early 1980's.

Achieving a balance between central and local operations and functions is another area where Dr. Glahn made critical contributions. This balance involves complex and evolving tradeoffs concerning the amount and location of equipment (e.g., computers) and specialized personnel, the origin of model and observational data, the location and technical capabilities of users, and the availability and cost of telecommunications. Dr. Glahn has continually worked to develop techniques and products that anticipate and capitalize on the capabilities at each level. The original MOS products were produced on the central computers at NMC and distributed from there to field offices and users. By the 1990's, a sophisticated local technique was also available that melded centralized MOS with data available only locally. In the National Digital Forecast Database, digital forecasts produced at local field offices using highly evolved, interactive techniques, are collected centrally, reconciled, and pieced together for ready access by users everywhere.

To accomplish all these things, Dr. Glahn has assembled and led a talented and diverse team of scientists and information system technologists. As the government shifted more reliance to the private sector, he astutely established contractual arrangements that smoothly integrated many skilled contractors into his team, not only training and directing their efforts, but effectively inculcating the spirit of achievement and dedication that has long distinguished TDL and its successor MDL. He is a consummate planner, leader, and manager.

Dr. Glahn has never been content merely to conceive grand visions and ask others to do the detail work. He also leads by example. He has always devoted the extraordinary additional effort to learn about new techniques and technology, mastering new programming languages and operating systems, and using them himself. He is a recognized expert in software design, programming, and testing. He developed personal expertise, internationally recognized, in devising effective codes for meteorological data that facilitate their transmission, storage, and use. His incredible dedication to all these efforts is legendary.

Dr. Glahn has extensively shared his knowledge and skills with the meteorological community. He has published as author or coauthor over a hundred papers and articles. He has presented papers at countless AMS meetings and arranged and conducted demonstrations of new techniques and systems. He has organized and lectured at national and international workshops on various topics, especially interpretation of NWP products. He received the Department of Commerce Gold and Silver Medals, the Department's highest awards, and the AMS Award for Outstanding Contribution to the Advance of Applied Meteorology in 1981.

The scope and importance of all these contributions clearly qualify Dr. Harry R. Glahn for the Cleveland Abbe Award.

Sincerely,
Douglas H. Sargeant
NOAA, retired

# Tribute to Dad

Harry Robert Glahn, our dad, grew up on a farm near Shelbyville, Missouri. Living with his parents, grandmother, and her family, he learned early to do chores, fish, and hunt. He married a farm-girl from a neighboring county, and they worked hard to put themselves through college and graduate school, often allowing themselves only the sole luxury of a weekly ice cream cone. During those frugal days, they had two boys—Gale and Gary.

As children, we drove from the East Coast to Missouri annually with our parents. There we enjoyed the best of what farm life offers grandkids: riding the wagon, driving the tractor beside Grandpa and Granddad, collecting eggs from the chicken house, fishing for catfish, and eating farm-fresh meals including vegetables from the garden, fish from one pond, and frog legs from another pond.

You know our Dad was committed to his career. But he was also committed to his family. He took us to church and enjoyed helping us with math and science, especially science experiments. A skilled camper, he participated with us in Cub Scouts and Boy Scouts, serving as our scoutmaster for a season.

In addition to our trips to the farms, our family enjoyed vacations together. We traveled across the USA twice to visit as many of the National Parks and National Monuments as we could. Our pop-up tent trailer and station wagon fit our parents' save-every-nickel yet adventurous style.

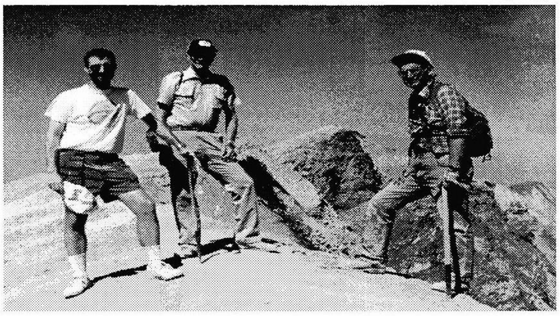
On one of the trips, when we boys were in our late teens, we stumbled across Dubois, a small town in Wyoming, where the locals boasted about a petrified wood forest in the nearby mountains. Despite the fact that our family generally followed a prescribed schedule that allowed for only a limited number of bathroom breaks, we were spontaneously diverted from the plan to follow a map to the petrified wood. When we found many specimens there that had washed down the creek from the forest, we determined to return.

Indeed, the next trip provided the best experiences of all our camping adventures. The four of us left base camp with packs on our backs and set out for a six-day journey in relatively uncharted territory. We trekked to the headwaters of one creek, over the mountain pass, and down the creek in the next valley, looping back to base camp. We marveled at God's creation displayed all around us as we soaked up the beauty of mountains and wildlife. We got bathroom breaks as needed on that portion of the trip, thanks to abundant shrubbery. In fact, to accommodate our privacy, Dad made up a signal, "cougar, cougar!" yelled in a high-pitched voice, that allowed us to alert other family members that it was "safe to proceed." As we entered the final day of puffing and sweating (thanks to all the trail souvenirs in our packs), Dad chanted, "Six days on the road, and we're gonna be home tonight!"

In 1987, Dad, along with mom, Gary, Sandi (Gary's wife), and others, backpacked the Grand Canyon from the south rim to Phantom Ranch at the bottom, and back up. In 1990, Dad summited Mount St. Helens (post eruption) in Washington with Gary and Willis Grafe, Gary's father-in-law. Both of these trips were strenuous and challenging—just what Dad likes.

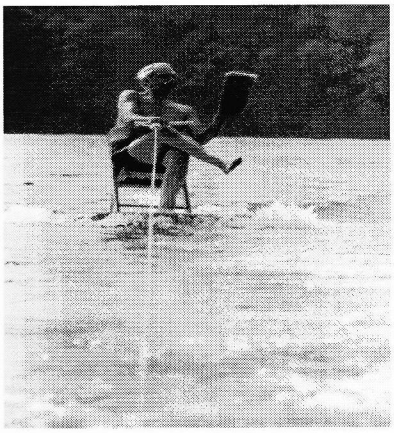
In addition to those trips, our parents bought a motorboat for water skiing. We enjoyed many outings to Lake Anna. We rode the waves on skis, zoomed across the water on a hydroplane Gary built in our basement with Dad's support, and skirted the surface on a homemade four-foot-diameter saucer.

Dad, a stiff competitor who played to win, found ways to outdo us on that saucer. Sometimes we would ski on it carrying a folding chair so we could sit as we glided across the lake. Not to be outdone, Dad was riding on the disk one afternoon when he pulled a plastic sack from his swim shorts and took something out. Next thing we knew, he was gliding across the lake reading a newspaper with a cigar in his mouth. When night fell and we went indoors, Dad was ready to beat us in an all-night game of "Risk."

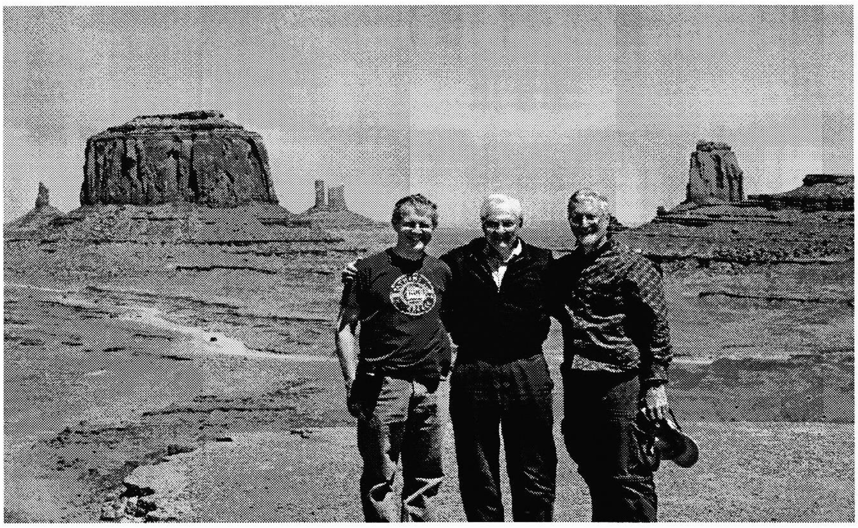


While Dad made sure we worked hard, he also saw to it that we had the support we needed to follow our dreams. He helped both of us and our wives earn college and/or master's degrees, and now the grandkids receive help with college expenses. He has also assisted us with home ownership, loaning us money (at no interest) for the down-payments. And he has made it possible for the family, though geographically far apart, to be together at least once each year.

That generosity has not been limited to serving only our family, however. Dad is the kind of guy to drive a car until it wears out precisely because he would rather spend his money on stuff that matters. As both of us have pursued careers that involve helping the less fortunate, he has supported us in word and action—from making it possible to dig wells in Africa to providing ways for needy kids in villages to get an education.



We thank God for a loving father who has guided us to be and do our best, has challenged us to finish whatever we've started, has helped make it possible to follow the desires of our hearts, and has modeled what it looks like to use one's talents and resources to make the world a better place.



Gale (and Tannie) Glahn, Falls Church, Virginia
Gary (and Sandra) Glahn, Dallas, Texas
July 2014

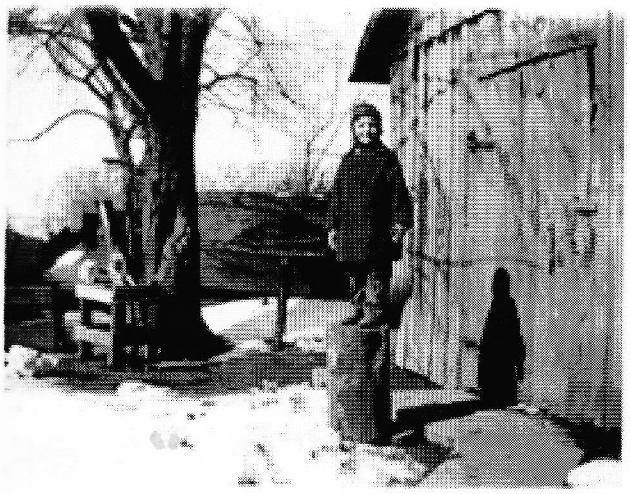
Meteorological Development Laboratory

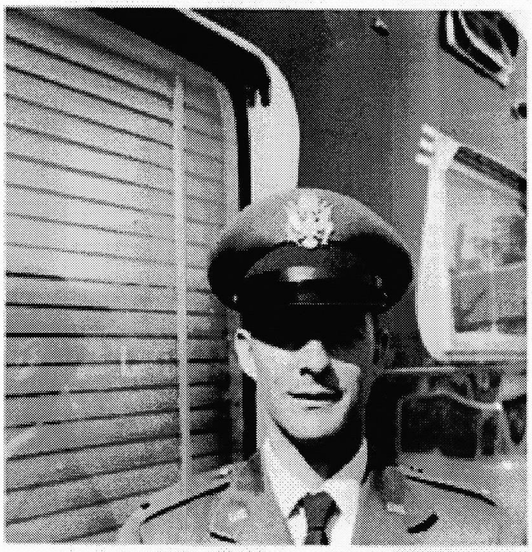
The Techniques Development Laboratory (TDL) was formed under Dr. Robert M. White, Director of the Weather Bureau (WB) in mid 1964. Charles F. Roberts was acting director for some months, a portion of that time being away at the Pennsylvania State University. The other senior person was Roger A. Allen, who led in the absence of a permanent director. Dr. George G. Cressman became director of the Weather Bureau in 1965 when Dr. White moved up to head the newly formed Environmental Science Services Administration (ESSA) of which the WB was a part. Dr. Cressman soon named Dr. William (Bill) H. Klein as the first permanent director of TDL, and he remained so until he moved up to head the Office of Systems Development, TDL's parent organization in 1975. The Weather Bureau was renamed the National Weather Service (NWS), and ESSA became the National Oceanic and Atmospheric Administration (NOAA) in 1970 under Dr. White.

Dr. Harry R. (Bob) Glahn, an original member of TDL in 1964, was named Deputy Director of TDL in 1970, after the retirement of Roger A. Allen who had held that post for several years. When Dr. Klein moved on, Dr. Glahn was named Director in 1976, with Dr. Cressman being the NWS director. In 1983, it became NOAA policy that the title "Director" be used only at the Office level, and the title became Chief instead of Director of TDL; that policy gradually eroded. As part of a reorganization of NWS Headquarters in 2000, while Gen. John (Jack) Kelly was NWS director, the laboratory was renamed the Meteorological Development Laboratory (MDL) and the Office of Systems Development was reorganized into the Office of Science and Technology (OST). After an interim period in which Dr. Glahn was acting director of OST, John (Jack) L. Hayes was selected as OST Director, with Dr. Glahn remaining as MDL director.

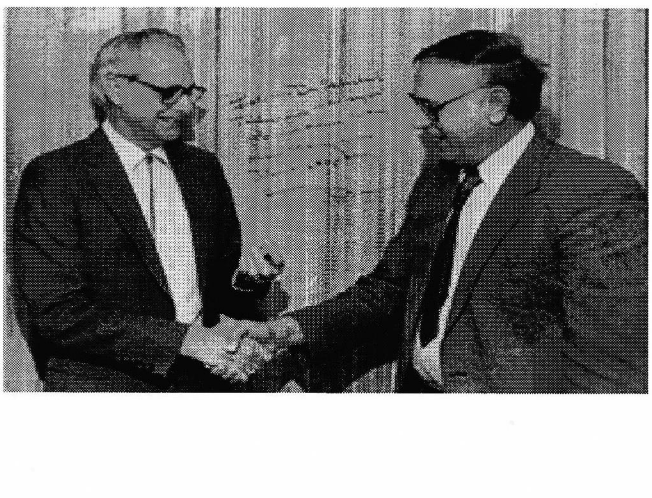
TDL/MDL has occupied three of the four locations of the headquarters of the Weather Bureau/NWS. When TDL was originally formed in 1964, personnel were primarily in the Annex to the Old Main building at 24th and M Streets, NW, Washington, D.C. In 1966, the NWS headquarters and TDL moved to the Gramax Building at 8060 13th St., Silver Spring, MD. From 1976-77, TDL occupied the William Building a couple blocks from the Gramax Building because of lack of space in the Gramax Building. In 1990, the NWS headquarters and TDL moved to Silver Spring Metro Center Building 2 (SSMC-2), 1325 East West Hwy, Silver Spring, MD, and has remained there to this day as part of the NOAA's SSMC Campus of four buildings.

During much of TDL's existence, some personnel were collocated with the National Meteorological Center (NMC)/ National Centers for Environmental Prediction (NCEP) at Federal Office Building 4 in Suitland, Md. and later at the World Weather Building in Camp Springs, Md. Coincident with the implementation of the reorganization and renaming to MDL, with few exceptions, all personnel were located at SSMC-2 starting in 2001. At its inception, TDL also had a small contingent at Sterling, VA, which was soon transferred to another division within OSD. Dr. Glahn, a charter TDL member and MDL's second Director, retired from federal service on July 3, 2012. Dr. Mike Farrar then became the third MDL Director in April 2014.






GOSHEN SCOUT
CAMP
GOSHEN, VA
TROOP



Dr Harry R. Glahn's name appears on over 180 publications, and as a first author on 138 of them. His papers appear in a variety of publications, ranging from AMS journals, technical memorandums, office notes, aerospace publications, book chapters, statistical journals, as well as many conference proceedings. Included here is a list of major publications, with Bob as a first author.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