# REAL-TIME ANALYSIS OF WEATHER PREDICTION ACCURACY

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## 1. INTRODUCTION

Large wildfire outbreaks are responsible for burning hundreds of thousands of acres of federal, state, and private lands every year, resulting in loss of property and life. Lightning is one of the primary causes of wildfire outbreaks in the western United States, and widespread dry thunderstorms can cause hundreds of fires in a single day. Land managers need timely information on when and where large outbreaks of wildfires are likely to occur to plan and position resources for a timely response.

Predicting the probability of sustained fire ignitions is a complicated exercise because many conditions must exist at the same time. Both current and future weather conditions are important, as well as fuel type, fuel loadings, and fuel moisture. Whether an ignition grows into a large fire depends on the location of the fire, resources available to extinguish the fire in a timely manner, and whether wetting rains occur after ignition. While we cannot incorporate estimates of resource availability, we do have the ability to assess risks based on weather and fuel conditions. The Wildland Fire Assessment System (http://www.wfas.net) provides an experimental product to estimate the risk of fire ignitions on the basis of previous lightning strikes and fuel condition (Sopko et al., 2007); however, this assessment is based on past and current conditions, not forecast conditions.

Weather forecasts can identify environmental conditions that give rise to increased fire danger. These conditions are important components of fire ignition potentials, fire danger rating systems, fire behavior predictions, and smoke dispersion modeling. Forecast weather conditions provide variables such as temperature, relative humidity, solar radiation, precipitation (or lack thereof), and wind variables that are used in models to predict where outbreaks of dry thunderstorms are likely to occur, the moisture content of fuels, and fire behavior. Clearly, weather forecast errors will propagate through the entire stream of predictions.

Further, fire weather forecasts are not always accessible—in terms of availability, clarity, and reliability—to those on the ground who need them. Much work has been done to validate mesoscale meteorology model output (Grimit and Mass, 2002), but most of the validation concerned surface variables without regard to fire effects. A national wildland fire weather needs assessment, conducted by the interagency Joint Action Group (JAG) for the Office of the Federal Coordinator for Meteorology (OFCM), recognized the need for improvements in the accessibility and reliability of fire weather forecasts and products (Office of the Federal Coordinator for Meteorological Services and Supporting Research, 2007). JAG members identified several fire weather forecast areas requiring urgent attention, including more statistical information on current accuracy and verification for fire weather forecasts, additional information regarding upper-level atmospheric parameters and stability conditions, improved spatial and temporal reliability of fuel moisture predictions, and standard representations of fuels information integrated with meteorological conditions and fire weather threats (Office of the Federal Coordinator for Meteorological Services and Supporting Research, 2007).

The USDA Forest Service (USFS) AirFire Team and Sonoma Technology, Inc. (STI) are working together to produce a system that will provide assessments of the confidence in fire weather forecasts, forecasted dry lightning probabilities, and forecasted fuel moisture conditions by integrating weather forecasts, the Rorig dry lightning prediction model (Rorig et al., 2007), Bothwell's predictions of precipitation amounts (Bothwell, 2005), and gridded fuels information. This system will produce digital maps of current, historical, and forecasted fire weather; dry lightning probabilities; and fuels ignition potentials. The approach used in the weather forecast assessment will provide end-users with real-time information about meteorological model bias, model reliability, and overall performance of

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fire weather forecasts used in predictions of ignition risk potential. The overall system will provide an easily accessible set of web-based products, including: (1) color contour displays of sustained ignition probability for the western United States at 1 km; (2) color contour displays of key meteorological parameter forecasts; and (3) information about confidence in the meteorological forecasts, time-series plots, and statistics that provide model-to-model and model-to-observation comparisons. A flow diagram of the forecast system is illustrated in **Figure 1**.

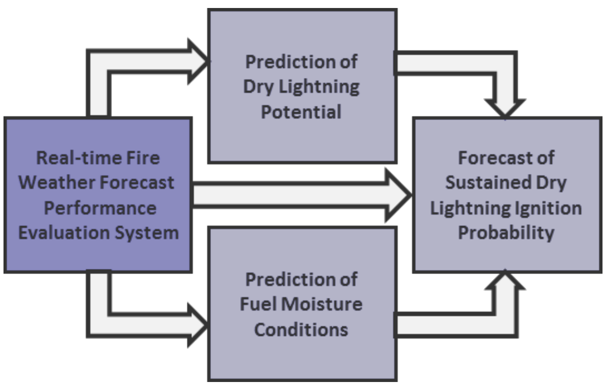


Fig. 1. Flow diagram of the sustained ignition probability forecasting system.

The real-time weather forecast performance evaluation system is the focus of this paper.

## 2. DATA ACQUISITION AND FORECAST EVALUATION SYSTEM

### *2.1 System Overview*

The forecast performance evaluation system provides information on weather predictions and uncertainty important to fire ignition risk. It routinely acquires observed and forecast meteorological data, and provides real-time evaluation/verification and uncertainty estimates of the model-predicted fire weather variables (both surface and aloft) that will be used in the fire ignition risk predictions. Intended to be a web-based information display system, results will be displayed as time-series and spatial plots that are continually updated as new observations and forecasts become available. Spatially and temporally integrated results of the real-time comparison of predicted and observed fire weather parameters (important to fire ignition risk) will be used as an indicator of model performance for the given model (e.g., North American Model, Global Forecast System, and National Digital Forecast Database) and model run.

Real-time model verification is a data-intensive process that requires a robust system for acquiring, processing, storing, and retrieving observed and modeled meteorological data. The system developed here consists of (1) a data acquisition system to manage and coordinate real-time data transfers and downloads; (2) extraction software to retrieve site-specific model data values and prepare data for database import; and (3) a database to facilitate storage and retrieval of observed and modeled meteorological data sets. Each component of this system, along with the data sources used, is represented in **Figure 2** and described below.

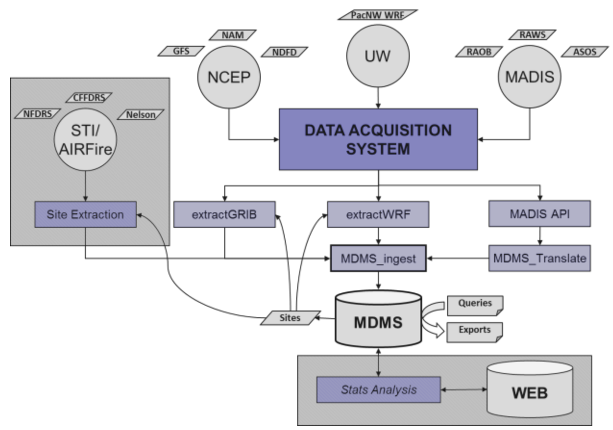


Fig. 2. Flow diagram of the real-time fire weather data acquisition and forecast evaluation system and its relation to the overall sustained ignition potential forecasting.

### *2.2 Data Acquisition System*

A data acquisition system (DAS) was developed to provide a single program for managing and coordinating continuous remote file transfer protocol (FTP) and local data transfers from multiple sources. Users can customize the details of DAS transfer jobs through a Windows-style INI initialization file. To add a new transfer job to the DAS, the user simply adds a new section to the INI file, customizes the details of the transfer job, and restarts the DAS. The INI specification accommodates filename structures often encountered with meteorological forecast data sets. Job scheduling is integrated into the DAS to eliminate the need to maintain a separate scheduler. The DAS also features a logging capability for tracking system failures, and command-line options for manually spawning one-time transfers.

The DAS is written in Python (version 2.6) and leverages the queue and threading modules from the Python standard library. Every minute, the main program scans the transfer times for all transfer jobs specified in the INI file and places any scheduled jobs into a transfer queue. An asynchronous runner thread performs file transfers as the jobs arrive in the transfer queue. The algorithm is illustrated by the flowchart in **Figure 3**.

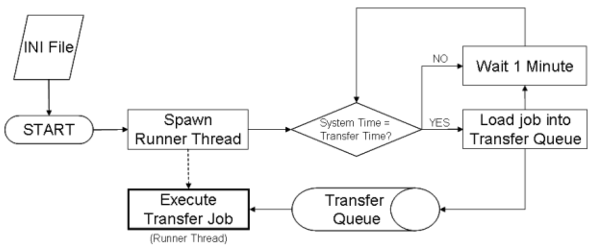


Fig 3. Flow diagram of the data acquisition algorithm.

### *2.3 Data Extraction and Processing*

Prediction of the probability of sustained ignition requires the seven meteorological parameters shown in **Table 1**. Also shown in Table 1 are the sources of observed and forecast data used in the forecast performance evaluation system.

Table 1. Sources of observed and forecast meteorological parameters used in the fire weather forecast performance evaluation system.

| Data Sources[1] | $T_{sfc}$ | $RH_{sfc}$ | E | Prec. | $u_{sfc}$ | $T_{aloft}$ | $T_{dp,aloft}$ |
|---|---|---|---|---|---|---|---|
| **Observed** | | | | | | | |
| ASOS | ✓ | ✓ | | ✓ | ✓ | | |
| RAWS | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| RTMA | ✓ | ✓ | | ✓ | ✓ | | |
| RAOB | | | | | | ✓ | ✓ |
| **Forecast** | | | | | | | |
| UW WRF | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| NDFD | ✓ | ✓ | | ✓ | ✓ | | |
| NAM | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| GFS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

[1] Data sources for seven meteorological parameters: surface air temperature ($T_{sfc}$); surface relative humidity ($RH_{sfc}$); solar radiation (E); precipitation (Prec.); surface wind velocity ($u_{sfc}$); aloft temperature ($T_{aloft}$); and aloft dew point temperature ($T_{dp,aloft}$)

The National Weather Service (NWS) Automated Surface Observing System (ASOS) network provides observations at hundreds of airports across the country. Though an important source of surface observations, ASOS sites are often not ideally situated to describe local fire weather conditions. Meteorological data from alternative observational networks, such as the interagency Remote Automated Weather Stations (RAWS) network, complement the ASOS network by providing data to support fire and land management decisions. RAWS stations also provide solar radiation data, which are important for evaluating modeled solar radiation predictions used to drive fuel moisture models. The National Centers for Environmental Prediction (NCEP) Real-Time Mesoscale Analysis (RTMA) combines surface wind, temperature, moisture, and precipitation observations with a NCEP 1-hr forecast background field. The RTMA 5-km spatial resolution matches the National Digital Forecast Database (NDFD) forecast product, as it was designed to provide gridded verification for the NDFD forecast product. The precipitation analysis is derived from a synthesis of rain gauge and Doppler radar reflectivity data. Direct measurements of upper-air meteorological parameters are spatially and temporally less numerous than surface measurements. The NWS radiosonde observation (RAOB) network provides twice daily upper-air pressure, temperature, and moisture data at nearly 80 sites in the United States.

Several different operational meteorological models are considered in the forecast performance evaluation system. These include the University of Washington (UW) regional Weather and Research Forecast (WRF) model at 4-km resolution for the Pacific Northwest, the NCEP North American Model (NAM) at 12-km resolution, and the NCEP global forecast system (GFS) model. The NAM, based on the WRF model, provides 84-hr forecasts over the continental United States. The GFS model, a global model, provides medium- and long-range forecasts out to 384 hours at 0.5-degree (~55 km) resolution. The NWS also provides two-dimensional gridded forecast data for the United States at 5-km resolution through the NDFD (Glahn and Ruth, 2003). The NDFD provides a seamless mosaic of digital forecasts from NWS field offices working in collaboration with NCEP.

The DAS is currently configured to acquire observed and modeled meteorological data sets from three sources: (1) the National Oceanic and Atmospheric Administration's (NOAA) Earth Systems Research Laboratory (ESRL) Global Systems Division (GSD) Meteorological Assimilation Data Ingest System (MADIS) (http://madis.noaa.gov); (2) NCEP; and (3) the UW Department of Atmospheric Sciences.

Surface and upper-air observations are acquired from the MADIS platform. MADIS provides a single point of access to quality-controlled meteorological observations from hundreds of networks and agencies around the world. The DAS currently acquires hourly surface data from the ASOS and RAWS networks, and twice-daily upper-air data from the RAOB network. MADIS data are extracted from their raw netCDF format with data dump utilities from the MADIS Applications Programming Interface (API), and prepared for database import by the ***mdms_translate*** program.

Model forecast data are acquired from NCEP in GRIB2 format. The DAS currently acquires forecast data from the NAM and GFS.. We currently acquire the NAM 84-hr forecasts for the continental United States (CONUS) at 12-km resolution and the global GFS seven-day forecasts at 1.0-degree (~110 km) resolution. The NDFD is a hybrid human-model forecast product, and is available at 5-km resolution for the CONUS. The DAS currently acquires 3-hourly forecast data at the 0000 UTC and 1200 UTC model initializations. Data are extracted from GRIB2 data at the observation sites and prepared for database import by the ***extractGRIB*** program, which uses the wgrib2 GRIB2 decoder.

The UW WRF system produces 72-hr forecasts initialized at 0000 and 1200 UTC with 4-km resolution. Because the hourly forecast data are large, a USFS computer hosted at UW runs a pre-processing script to "thin" the forecast data by selecting only certain variables before transfer. The thinned forecast data are acquired in the native WRF output format by the DAS, and extracted at the observation sites and prepared for database import by the ***extractWRF*** program.

### *2.4 Database Platform*

A PostgreSQL database platform called the Model Data Management System (MDMS) was developed to facilitate efficient storage and retrieval of modeled and observed meteorological data. The MDMS stores site-specific data using a minimized data table for optimal storage and retrieval, and accommodates the unique challenges posed by model data sets with multiple daily cycles. A Java-based automated ingest system is also built into the MDMS to import modeled and observed data in real time as they are acquired and processed. Though the MDMS was developed for the fire weather forecast performance evaluation system, its design is quite generic and flexible.

Data are obtained from MDMS by building queries and stored procedures (which codify a pre-defined set of queries). Interactive tools, such as *pgAdmin*, can be used to explore the database and query MDMS data interactively. Database connections can also be established through programming languages such as R or Python to perform automated queries and robust statistical analyses.

### *2.5 Forecast Analysis and Evaluation*

Various analysis methods for establishing confidence levels for the meteorological models considered have been investigated. These include inter-comparison and evaluation methods such as time-series analysis, standard model performance metrics, and skill scores. A retrospective evaluation of the meteorological predictions, used to drive the probability of the sustained ignition prediction system, provides a basis for quantifying the reliability of meteorological forecasts for fire weather purposes. Currently underway, this evaluation will complement the daily real-time comparisons. The historical analysis will allow the real-time model performance to be placed in historical context and will be used to develop categories of forecast confidence. Further, we will perform regression analyses and develop predictions of future model performance (one to seven days) based on recent model performance. These investigations contribute to a confidence rating system for the meteorological forecasts.

## 3. PRELIMINARY RESULTS

The DAS underwent an initial testing phase with data from MADIS (ASOS and RAWS surface data) and NCEP (NAM 12-km 0000 UTC and 1200 UTC 3-hourly forecasts; and GFS 1.0-degree 0000 UTC and 1200 UTC 3-hourly forecasts). The data, including temperature, relative humidity, wind speed, wind direction, solar radiation, fuel moisture, and precipitation, were ingested by the MDMS. Queries were developed to retrieve data from the MDMS for initial investigation of model performance evaluation analyses.

Standard model performance metrics (e.g., mean bias and error) were computed for sets of data queried from the MDMS. These included NAM and GFS surface temperature forecasts, as well as observations, for two different time periods and locations. The performance statistics for each model were considered by forecast period, ranging from a one-day forecast period up to a three-day forecast period for the NAM and seven-day forecast for the GFS. Similar statistics were also computed for the persistence forecast method, which serves as a reference model for determining forecast skill scores.

A sample of results from this initial analysis is illustrated in **Figure 4** for NAM forecasts of temperature at 6:00 p.m. at the Boise Air Terminal (KBOI) meteorological station for an 11-day time period. The figure demonstrates the performance of the model by comparison of the observed temperature (green bars) to the one-day (open circles), two-day (orange squares) and three-day (yellow triangles) NAM forecasts on 8/19/2011 and the previous seven days. It also shows the performance of NAM temperature forecasts (solid black circles) for the next three days (i.e., 8/20, 8/21, and 8/22/2011). The error bars on the three "future" day forecasts indicate the mean error for the forecast based on the model performance over the previous seven days.

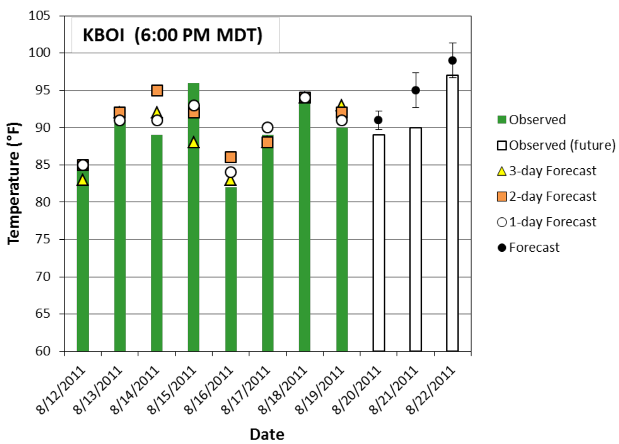


Fig. 4. Illustration of NAM forecast performance analysis for Boise Air Terminal (KBOI).

Figure 4 is an example of the type of intermediate output that the real-time fire weather forecast evaluation system could provide to the user. On any given day, the user could visualize the performance of a model at a location of interest during the recent past, and view its expected performance for the near future (indicated by the error bars in Figure 4). Of course, in real time, observations for future days do not exist. Inclusion of the "future" observations in Figure 4 simply allows comparison with the forecasts in this demonstrative example. Moreover, these observations lend insight to the potential need to consider a longer time period in computing mean forecast error, or another statistic to bound forecast uncertainty.

## 4. SUMMARY AND CONCLUSIONS

An automated data acquisition and forecast evaluation system was developed that is capable of real-time analysis of weather forecast accuracy. This system is suitable for providing assessments of fire weather predictions and their impact on forecasts of dry lightning potential, fuel moisture, and sustained ignition probability.

### *4.1 Future Work*

In the next phase of this research, we will perform additional forecast evaluation assessments and, based on their results, develop a series of analysis tools and products. These tools and products will be integrated into a web-based information display system.

Further, we will implement the full sustained ignition probability forecasting system shown in Figure 1 and investigate how the uncertainties in the weather predictions propagate through to the sustained fire ignition predictions.

Finally, we will develop spatial plots of the resulting sustained ignition probability (see **Figure 5**) and a "dashboard" type summary of confidence in the predictions suitable for use by land managers (see **Table 2**).

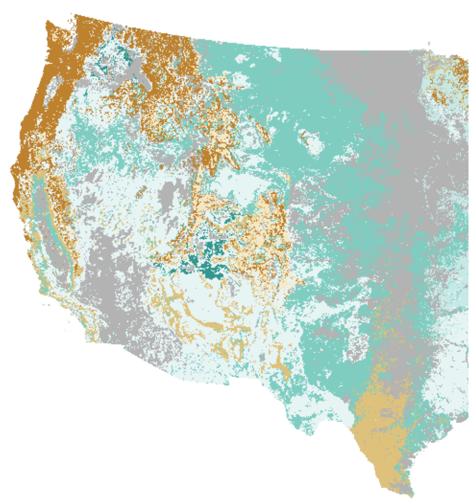

Fig. 5. Example of the type of spatial plot to be used in presenting sustained ignition probability.

Table 2. Example of a forecast confidence dashboard.

| Forecast Source | Forecast Length (days) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| UW-WRF | | | | | | | |
| NAM | | | | | | | |
| GFS | | | | | | | |
| NDFD | | | | | | | |
| Persistence | | | | | | | |

No Forecast Available
High Confidence
Medium Confidence
Low Confidence
No Confidence

### *4.2 Extension of the System to Air Quality*

While the focus of the research described in this paper is fire weather, the system could just as well be used in air quality applications. The system could easily be extended to parameters needed for estimating emissions, dispersion, transport, deposition, chemical reactions, and ultimately air pollutant concentrations.

## 5. ACKNOWLEDGMENTS

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