857 Improving Lightning Density Guidance with Calibrated Probabilities from Ensemble Model Output

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1. INTRODUCTION

Lightning-ignited wildfires are responsible for the majority of acreage burned across the United States (insert ref). Thunderstorm and lightning guidance are imperative to fire weather forecasts, which are used by wildland fire managers when making decisions about resource allocation and suppression tactics. The Storm Prediction Center (SPC) is responsible for thunderstorm and fire weather outlooks for the conterminous United States (CONUS), which helps provide decision support for local National Weather Service (NWS) weather forecast offices and wildland fire managers. SPC utilizes a variety of forecast guidance to produce these outlooks including the SPC Short Range Ensemble Forecast (SREF)-based calibrated thunderstorm probabilistic guidance (SREF CalThunder) (Bright et al. 2005; Bright and Grams 2009) and SPC Perfect Prog (nosis) Forecast (PPF) (Bothwell 2002, 2005, 2006, 2008).

The SREF produces forecasts on a 40-km grid every hour to 39 hours and every three hours out to 87 hours with forecast cycles at 03, 09, 15, and 21 UTC. The SREF has 26 members and two dynamical cores: the Nonhydrostatic Multiscale Model on the B-grid (NMMB) and the Advanced Research Weather and Research Forecast (WRF-ARW) model (Du et al. 2006; SPC 2017). The development of the SREF-based calibrated thunderstorm probabilities begins with the probability that the cloud physics thunder parameter (CPTP) will be greater than one and the probability of receiving at least 0.01" of precipitation (Bright et al. 2005). These two probabilities are then binned at 10% intervals and paired into one of the 121 possible probability bins (Bright et al. 2005). The cloud-to-ground (CG) lightning frequency with inverse-distance weighting (i.e., 1/radius) (IDW) is assigned to each one of the probability bins, and the weights associated with observed National Lightning Detection Network (NLDN) CG lightning is divided by the total weights. This process is conducted for each forecast cycle and hour and at each grid point using one year's worth of data to generate the calibrated probabilities for ≥ 1 and ≥ 100 CG lightning flashes.

The PPF utilizes the Global Forecast System (GFS) and archived CG lightning data to generate probabilistic equations for CG lightning on a 40-km grid for the CONUS and Alaska (Bothwell 2002). Methodology, previous forecasts, and verification of these forecasts can be found in Bothwell (2002, 2005, 2006, 2008). The GFS PPF generates probabilities of ≥ 1, ≥ 10, and ≥ 100 CG lightning flashes at 3-hour and 6-hour intervals.

Our objectives are three-fold: 1) verify the SREF CalThunder and GFS PPF probabilistic guidance for ≥ 1 and ≥ 100 CG lightning flashes; 2) objectively determine the appropriate number of CG lightning flashes for a CG lightning density forecast and implement either the SREF CalThunder or GFS PPF techniques depending on which preforms best during the comparative verification; and 3) verify the new CG lightning density probabilistic guidance.

2. VERIFICATION OF CURRENT METHODS

Comparative verification was conducted on a 40-km grid for the SREF CalThunder and GFS PPF using NLDN CG lightning data. The verification covered parts of a three-year period (list dates) when archived forecasts were available from both methods, and focused on forecasts ≥1 and ≥100CG lightning flashes. SREF CalThunder three-hour forecasts out to 87 hours from the 09 and 21 UTC forecast cycles, and GFS PPF three-hour forecasts out to 84 hours from the 12 and 00 UTC forecast cycles for ≥1 and ≥100 CG lightning flashes were chosen for the verification. Probability of detection (POD), false alarm rate (FAR), receiver operating characteristic (ROC) plots, area under the curve (AUC), and reliability were all calculated to evaluate the forecasts.

Figure 1 shows the ROC plots with AUC values, and Fig. 2 shows the reliability diagrams for all four forecasts. SREF CalThunder outperforms the GFS PPF for both ≥1 and ≥100 CG lightning flashes and demonstrates accurate and reliable forecasts. Other forecast metrics were calculated including Brier Skill Score (not shown) that supported the SREF CalThunder as providing better forecast guidance than the GFS PPF.

3. NEW LIGHTNING DENSITY

When examining observed 1- and 3-hour CG lightning flash totals ranging from 5 to 200 CG lightning flashes (binned every 5 CG lightning flashes), an inflection point emerged on the distribution between 20 and 30 CG lightning flashes (insert figure). When at least one CG lightning flash occurs, more than 80% of all 1-hour CG lightning flash totals occur below 20 CG lightning flashes and 81% of all 3-hour CG lightning flash totals occur below 30 CG lightning flashes. A density between 20 and 30 CG lightning flashes occurs rarely enough to provide additional insight on CG lightning flash potential than the ≥ 1 CG lightning flash guidance to forecasters, but it is not too rare as to inhibit effectively calibrating to and forecasting that density value(s). Utilizing the calibration method from the SREF CalThunder, multiple grid point distance and CG lightning flash frequency weighting, statistical calibration, and smoothing methods were tested on CG lightning density thresholds of 20, 25, and 30 CG lightning flashes during 1-hour (out to a 39-hour forecast) and 3-hour periods (out to an 87-hour forecast).

Based on preliminary results, the best method for a new lightning density probabilistic forecast for ≥ 25 CG lightning flashes utilizes the calibration method from SREF CalThunder with IDW ($(1/\sqrt{(i^2 + j^2)})$; where i is the number of grid points away from the grid point being calibrated in the x-direction and j is the number of grid points away from the grid point being calibrated in the y-direction) up to five grid points away in the x and y directions. When CG lightning flashes exceed 25, the IDW is utilized and that value is added to ‘hits’ and ‘totals’ for the grid point being evaluated at that forecast cycle and hour. However, when lightning occurs but is less than 25 flashes that IDW value is multiplied by the inverse difference between 25 and the number of CG lightning flashes for the grid point being evaluated at that forecast cycle and hour and added to both 'hits' and 'totals'. When there are no CG lightning flashes, the IDW is added to 'totals'. In addition to the three hours of lightning data used to calibrate against, one hour before and one hour after the three-hour period are included but those amounts are halved. One year of NLDN CG lightning and SREF model data is utilized to calibrate the forecasts with the probabilities calculated by dividing 'hits' by 'totals' at every grid point, forecast cycle and hour, and each binned probability pair. Once the probabilities are generated, they are smoothed using the surrounding 24 grid points within a +/- 2 grid points in x-y directions.

Figure 3 show the ROC plots with the AUC value and reliability diagrams for the new SREF CalThunder density (≥ 25 CG) probabilistic forecasts. These plots used the calibration time period from 1 December 2015 to 30 November 2016 and the verification time period was from 1 December 2014 to 30 November 2015. The forecasts demonstrate reliability through 50% after which the sample size becomes much smaller, and have excellent AUC values with reasonable POD at low probabilities. The calibration and verification time periods were switched for comparison and the results were similar (not shown).

4. SUMMARY AND FUTURE WORK

Comparative verification was conducted on a 40-km grid for the SPC SREF CalThunder and the GFS PPF for thunderstorm (lightning) forecasts using NLDN CG lightning data. Standard metrics (e.g., reliability, ROC scores) indicated the SREF CalThunder demonstrated more reliable and accurate forecasts than the GFS PPF (Figures 1-2). Accordingly, the SREF-based technique was utilized to develop improved probabilistic lightning density guidance. The SPC SREF calibrated thunder approach was refined to improve lightning density guidance, including objectively analyzing climatological lightning flashes for identifying an appropriate threshold for lightning density. Refining the SREF calibrated thunder approach yielded reliable and accurate probabilistic lightning density (≥ 25 CG) forecasts (Figure 3). The new SREF CalThunder for lightning density will be available experimentally within SPC in the near future for further testing by operational forecasters while the current SREF CalThunder (≥ 1 CG) is being implemented in version 3 of the National Blend of Models.

Time periods of 1, 4, 6, 12, and 24 hours are also being examined for the new SREF CalThunder lightning density guidance. After examining those time periods, convection allowing models (CAMs) will be utilized to generate probabilistic lightning density forecasts as the project moves forward. This multi-year project will provide a unified and consistent approach for improved, calibrated probabilistic lightning prediction capabilities across a range of temporal scales, starting days in advance and leading to frequently updated high temporal/spatial information in the short-term to better address potential for significant lightning events. The lightning, lightning density, and dry lightning prediction products are proposed to be part of a foundational national convective forecasting guidance system that would promote consistency across the NWS and support multiple service dimensions associated with thunderstorm hazards.

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FIGURES

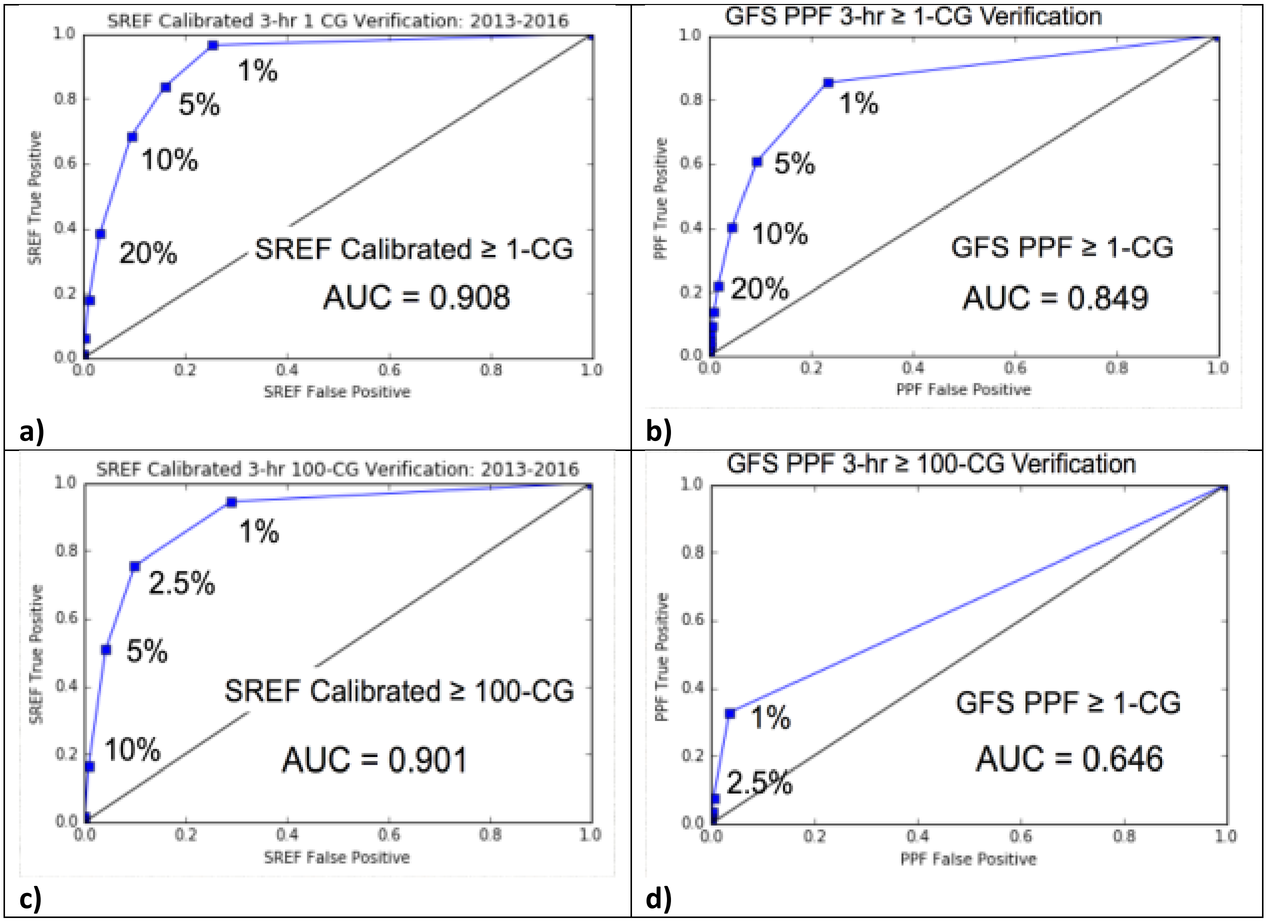

Figure 1. a) ROC plot with probabilistic forecast thresholds of 1, 5, 10, and 20% noted, and AUC value for current SPC SREF Calibrated Thunder probabilistic forecasts for ≥1 CG using data for a subset of 2013-2016; b) same as a), except for GFS Perfect Prog probabilistic forecasts for ≥1 CG using data from the same time period; c) same as a), except for SPC SREF Calibrated Thunder probabilistic forecasts for ≥100 CG with probabilistic forecast thresholds of 1, 2.5, 5, and 10% noted; d) same as c), except for GFS Perfect Prog probabilistic forecasts for ≥100 CG with forecast thresholds of 1 and 2.5% noted.

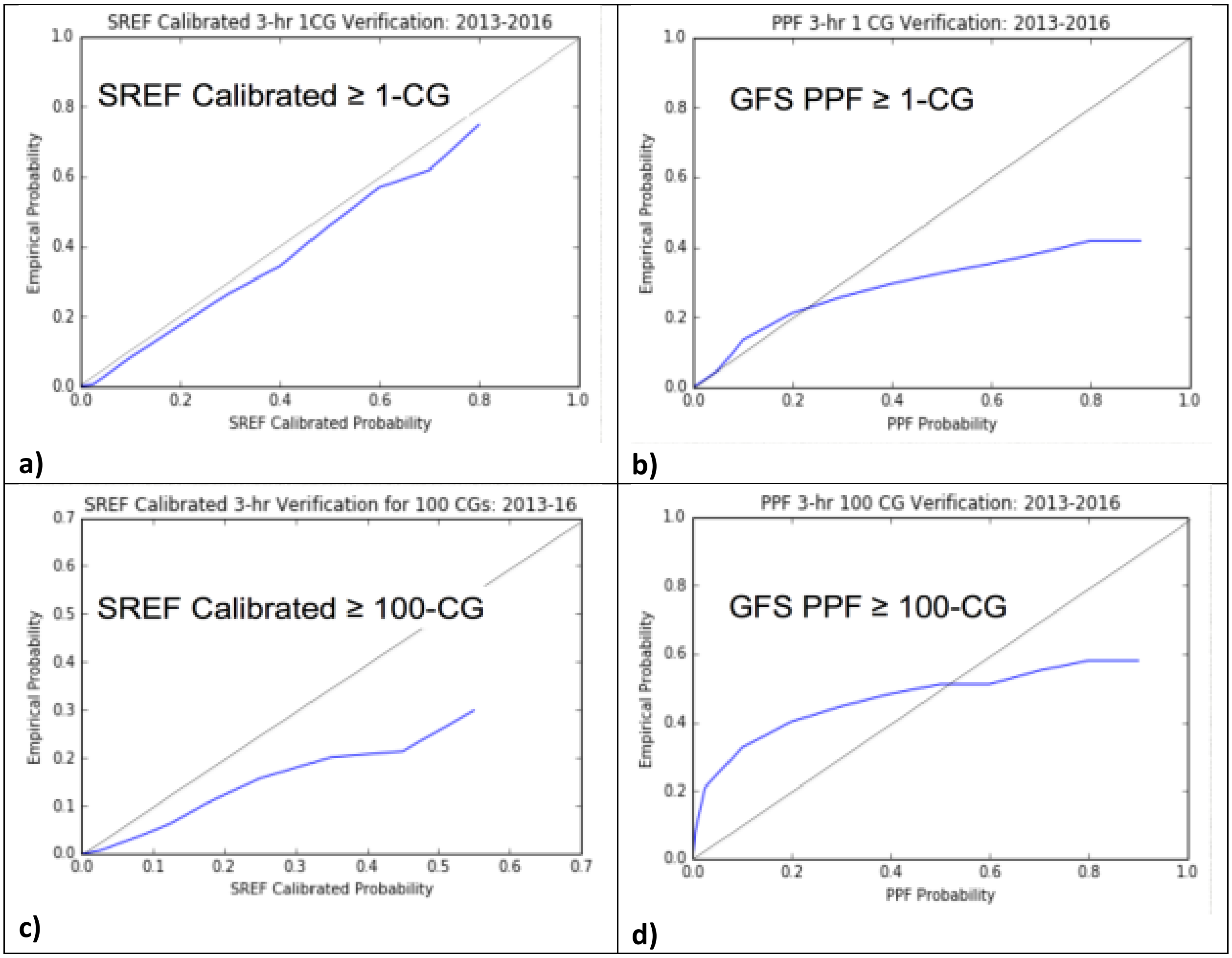

Figure 2. a) Reliability diagram for current SPC SREF Calibrated Thunder probabilistic forecasts for ≥1 CG using data from a subset of 2013-2016; b) same as a), except for GFS Perfect Prog probabilistic forecasts for ≥1 CG using data; c) same as a), except for SPC SREF Calibrated Thunder probabilistic forecasts of ≥ 100 CG; d) same as c), except for GFS Perfect Prog probabilistic forecasts for ≥ 100 CG.

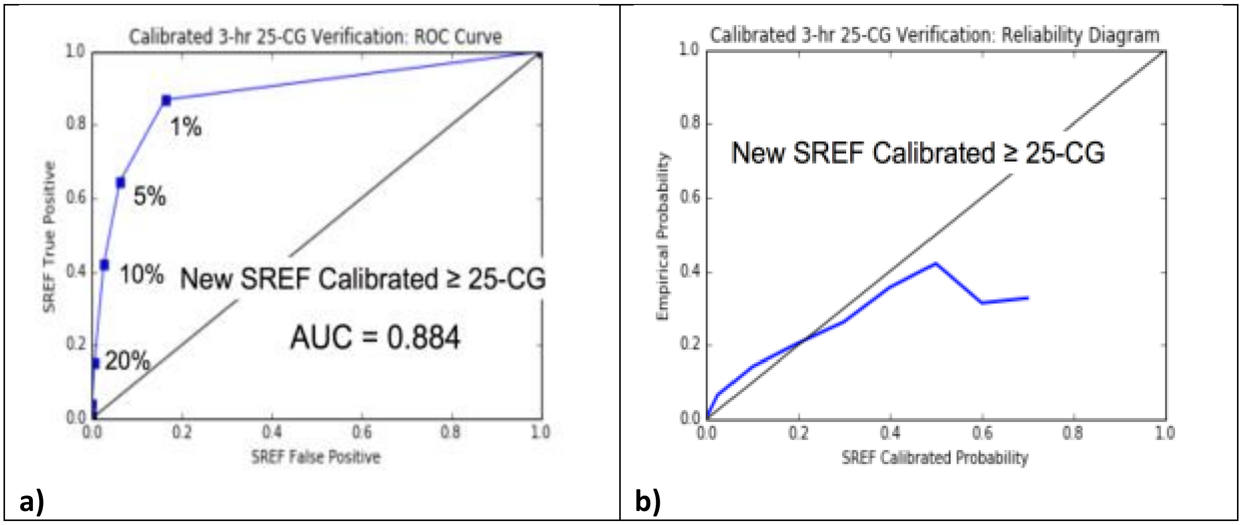

Figure 3. a) ROC plot with probabilistic thresholds of 1, 5, 10, and 20% noted, and AUC value for new SPC SREF Calibrated Thunder probabilistic forecasts for ≥25 CG using verification data from 12/1/14 – 11/30/15 and calibration data from 12/1/15 – 11/30/16; b) Reliability diagram for new SPC SREF Calibrated Thunder probabilistic forecasts for ≥25 CG for the same time period as a).