Development and Demonstration of a Lightning Density Product at the Ocean Prediction Center

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CONTENTS

ABSTRACT

Lightning data is a valuable forecasting tool, especially over the oceans where surface weather stations and radars are lacking. A gridded lightning density product was developed using the Global Lightning Dataset (GLD360) for demonstration at the National Weather Service (NWS) Ocean Prediction Center (OPC) during summer 2013. The GLD360 lightning density product is available at 2-min, 5-min, 15-min, and 30-min intervals on an 8 km x 8 km grid. This product makes lightning intensity more evident than the legacy GLD360 stroke location product, and also simulates the way that the GOES-R Geostationary Lightning Mapper (GLM) data can be displayed. Forecasters use the lightning density product to observe convection beneath cold-cloud shields, locate convective maxima within larger features, validate model output, and support other decision-making (e.g., adjustment of local wind fields). This new product augments existing OPC tools for evaluating offshore convection, and also prepares forecasters for the GOES-R GLM era.

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1. INTRODUCTION AND BACKGROUND

A lightning density product was developed during spring 2013 for demonstration at the National Weather Service (NWS) Ocean Prediction Center (OPC). The National Environmental Satellite, Data, and Information Service (NESDIS) Center for Satellite Applications and Research (STAR) and the NWS developed the product using data from Vaisala's Global Lightning Dataset (GLD360) as part of the Geostationary Operational Environmental Satellite R-Series (GOES-R) Proving Ground (PG) efforts. The project introduces forecasters to a continental-scale lightning density product to prepare them for the planned GOES-R Geostationary Lightning Mapper (GLM). The project seeks to improve the OPC's ability to evaluate offshore convection, incorporate forecaster feedback to improve the lightning density product, and refine training methods prior to wider distribution. This paper describes the development of the lightning density product and related training materials, the forecasters' experiences using the product, and benefits for the GOES-R program. The remainder of this section describes the operational use of lightning data, provides background on the GLM and the GLD360, and elaborates on the project goals.

Improving lightning detection technology has expanded the use of lightning data by both researchers and operational forecasters. Total lightning data (i.e., intra-cloud [IC] plus cloud-to-ground [CG]) are useful for severe weather warning operations (Goodman et al. 1988; MacGorman et al. 1989), due to the relationship between lightning frequency and updraft intensity (MacGorman et al. 1989, 2008; Deierling and Petersen 2008). Rapid increases in total lightning (colloquially know as lightning jumps; Williams et al. 1999) often precede severe weather occurrence (Goodman et al. 1988; Williams et al. 1989, 1999; MacGorman et al. 1989, 2008), motivating researchers to develop operational lightning jump algorithms to aid during severe weather warning operations (Gatlin 2006; Gatlin and Goodman 2010; Schultz et al. 2009, 2011). Lightning data also can help improve satellite-derived rainfall estimates, which are especially useful in data sparse regions (Pessi and Businger 2008). These improved rainfall estimates and latent heating profiles can be assimilated into numerical weather prediction models, resulting in improved precipitation, surface wind, and atmospheric pressure forecasts (e.g., Pessi and Businger 2009). Lightning data also are used to improve tropical cyclone intensity forecasts (DeMaria and DeMaria 2009; Fierro and Reisner 2011).

Many studies have examined the relationship between lightning activity and other storm parameters over land (e.g., Goodman et al. 2005; Deierling and Petersen 2008; Rudlosky and Fuelberg 2013), but there is significantly less information about lightning in oceanic storms. Lightning occurs less frequently over the ocean than over land (Brooks 1925; Zipser and Lutz 1994; Christian et al. 2003; Cecil et al. 2005), but there is a tendency for stronger lightning strokes over the ocean (Biswas and Hobbs 1990; Rudlosky and Fuelberg 2010; Hutchins et al. 2013; Said et al. 2013). For similar 85 GHz polarization-corrected brightness temperatures and radar reflectivity properties, lightning flashes are more likely over land than over the ocean (Toracinta and Zipser 2001; Liu et al. 2012). Tropical oceanic mesoscale convective systems (MCS) have weaker vertical velocities than tropical continental MCS, and the weak vertical velocities typical of oceanic storms prevent the lifting or generation of large ice particles necessary for lightning production (Zipser and Lutz 1994).

Although the frequency and strength of lightning over the ocean has been evaluated, the relationship between lightning and other storm characteristics over the ocean has received less attention. Oceanic thunderstorms have higher 20 dBZ echo top and larger horizontal extent than continental thunderstorms, but radar reflectivity is less likely to exceed 30 and 40 dBZ at cold temperatures (Liu et al. 2012). Previous studies on lightning properties over the ocean have focused on the tropics and subtropics, but there is significant regional variation in lightning characteristics (Liu et al. 2012). For example, there is a recurrent region of near stationary convection with enhanced lightning activity over the Gulf Stream off Cape Hatteras in winter (Hobbs 1987; Biswas and Hobbs 1990). As knowledge of oceanic thunderstorms increases, so will the operational benefits of global lightning datasets.

The GLD360 is among a number of available lightning data sources. Others include Vaisala's National Lightning Detection Network (NLDN), the World Wide Lightning Location Network (WWLLN; operated by the University of Washington), and Earth Networks Total Lightning Network (ENTLN). Each of these networks has strengths and weaknesses in terms of detection efficiency and location accuracy, types of lightning detected, and areal coverage, but the GLM will represent a significant improvement over these ground-based networks. The OPC presently receives a merged feed from Vaisala's NLDN and GLD360 networks. The legacy GLD360 product at OPC plots the locations of positive and negative flashes using '+' and '-' symbols, respectively. This product is helpful for indicating locations of lightning occurrence, but it remains difficult to quantify the lightning intensity or make quantitative comparisons between different convective areas using this product alone. The lightning density product solves this issue.

The GLD360 is a long-range lightning detection network developed and operated by Vaisala, Inc. The network's ground-based sensors detect the very low frequency (VLF) radio waves emitted by lightning (Said et al. 2010). Global coverage is provided with relatively few sensors because the ionosphere and the Earth's surface trap the VLF radio waves emitted by lightning, which can propagate thousands of kilometers with minimal attenuation (Crombie 1964; Dowden 2002). The network determines the distance of propagation and time of arrival by correlating the shape of the received waveform with those contained in the sensor's bank of expected waveforms (Said et al. 2010). Each sensor has its own bank of predetermined waveforms, which are catalogued by day/night profile and distance. Lightning discharges primarily are located using the arrival time, but also using a combination of arrival azimuth angle, estimated range, and estimated amplitude (Said et al. 2010). Since CG lightning emits more strongly in the VLF range than IC lightning (Pierce 1977), the GLD360 detects primarily CG lightning. The network also detects some strong IC pulses, but does not distinguish between CG and IC. The GLD360 reports the timing and location of lightning strokes, as well as the polarity and estimated peak current (Said et al. 2010). The polarity and estimated peak current are not presently used in the lightning density product.

The planned GOES-R GLM is a high-speed event detector operating in the near infrared (i.e., 777.4 nm), which will detect both IC and CG flashes by measuring changes in cloud top radiance of individual pixels (Goodman et al. 2013). The GLM algorithms are based on those developed for the National Aeronautical and Space Administration

(NASA) Lightning Imaging Sensor (LIS; Christian et al. 1992) and Optical Transient Detector (Boccippio et al. 2000). The LIS is housed on the Tropical Rainfall Measurement Mission (TRMM) satellite and remains operational, but the Optical Transient Detector is no longer in use. A lightning event is defined as an illuminated pixel that exceeds the brightness threshold, and lightning groups consist of simultaneous events occurring in adjacent pixels (although groups can consist of a single event). The GLM algorithm will combine groups that occur within 330 ms and nearer than 16.5 km to define flashes (Goodman et al. 2013). The LIS is in low-earth orbit, providing ~90 sec snapshots of individual storms along its orbital track (Christian et al. 1999). This makes LIS useful for developing long-term lightning climatologies (i.e., Christian et al 1999; Cecil et al. 2012), but limits its operational use. Conversely, the GLM will be mounted on a geostationary satellite and provide continuous real-time total lightning data over nearly the entire hemisphere, increasing its weather forecasting applicability. The GLM will provide nearly uniform spatial coverage at 8 km x 8 km resolution with an expected DE of approximately 86% (Goodman et al. 2013).

Oceans lack the weather stations and radar coverage that is present over the contiguous United States, increasing the importance of remotely-sensed lightning datasets in these regions. Evaluating offshore convection has been a significant forecast challenge for the OPC and one which the center is focused on addressing. A major goal of this project is to augment existing OPC tools and datasets to improve their diagnosis of offshore convection. Shadowing forecasters during routine operations provides the opportunity to incorporate their experiences into an improved GLD360 flash density product. This project shows that the GLD360 lightning density product provides valuable information to national forecast centers and that it will serve as an important tool in preparation for the planned GOES-R GLM.

The second section of this paper describes the development of the GLD360 lightning density product. Section 3 then describes the product demonstration, including the introductory product presentation and the development of training materials. Results of the product demonstration are discussed in section 4, including forecaster reactions to the product, situations where the product was determined to be most useful, and suggestions for making the training more effective. The final section summarizes our findings regarding the operational use of the GLD360 lightning density product, benefits of the developer-forecaster collaboration, and preparations for the future GLM.

2. THE GLD360 LIGHTNING DENSITY PRODUCT

The GLD360 lightning density product makes lightning intensity more visually evident and simulates a way that the GLM data can be displayed. The GLD360 was chosen because it provides full ocean-basin coverage with relatively high detection efficiency. The lightning density product was developed using archived GLD360 data for significant convective events over both land and ocean. As previously mentioned, the OPC presently receives a merged feed from Vaisala's NLDN and GLD360 networks, and displays the data as '+' or '-' symbols to indicate the locations of positive and negative strokes, respectively. The lightning density algorithm assigns each lightning stroke to a grid and calculates the lightning frequency within individual grid boxes.

Lightning density is calculated by summing the total number of strokes in each 8 km x 8 km grid box during a period of time, then dividing by the period of time (in minutes) and the area (64 km^2) to get a value in strokes per km^2 per min. This value is then scaled (multiplied) by 1000 to make the numbers large enough for display in the National Center Advanced Weather Interactive Processing System (NAWIPS). The lightning density is available at 2-min, 5-min, 15-min, and 30-min intervals. This allows forecasters to examine the short-term evolution of convective storms or to get a broader sense of the convective activity. Different time periods also facilitate use alongside other meteorological products that are available at different time increments (e.g., radar [~5 min] and GOES imagery [15 and 30 min]). Dividing by the number of minutes normalizes the lightning density product, so a longer time period does not necessarily result in greater lightning density values. The 2-, 5-, 15-, and 30-min products share the same units and scale.

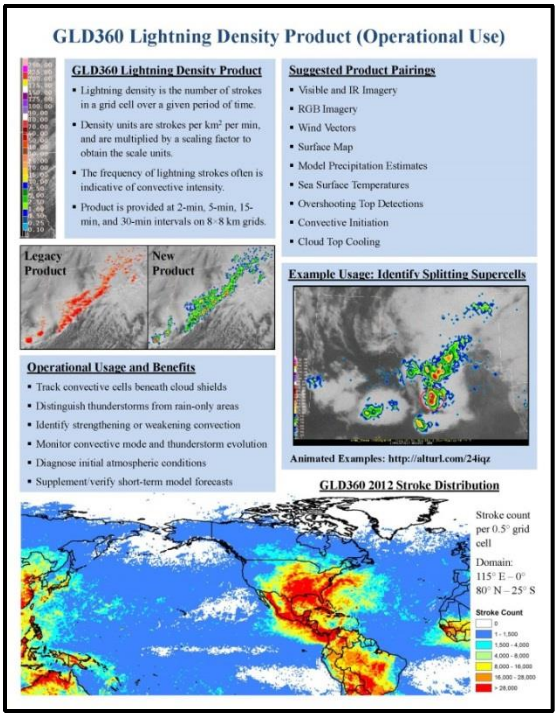
Applying the lightning density algorithm to archived cases helps to examine the display and ensure that the product functions properly. The lightning density product also is compared with other archived data, including infrared and visible imagery, the Overshooting Top Detection (OTD) product (Bedka et al. 2010), radar (for portions of cases occurring near shore), and scatterometer surface winds. Viewing the lightning density product in conjunction with other meteorological data provides an opportunity to understand how forecasters use the product in operations. These comparisons also underscore the need to better understand the relationships between lightning and other storm parameters over the ocean.

3. DEMONSTRATION AT THE OCEAN PREDICTION CENTER

Training and reference materials were developed through collaboration between the University of Maryland/Cooperative Institute for Climate and Satellites (CICS-MD), NOAA/NESDIS/STAR, and the OPC. The OPC forecasters received a training presentation as an introduction to the GLD360 lightning density product. The training presentation included a description of the GLD360 lightning density product, examples from archived cases, an overview of the GLM and GLD360 detection methods and capabilities, and examples of situations where the product can be used. This training maximizes the benefits to forecasters by providing them the opportunity to ask questions to better focus the training on their needs. The forecaster training experience at OPC and other national forecast centers also will help develop future GLM training methods.

A few important points are emphasized during training. The actual stroke density values are less important than the ability to identify and compare lightning intensity in different regions. The values are scaled to make them large enough for display in NAWIPS, so the actual lightning density is not immediately evident from the value displayed. It is also important to highlight the effect of the grid on the lightning density calculations. The grid is static, so the position and movement of storm cells determines the portion of a grid box they occupy, and the speed of the storm cells will determine how much time they spend in a grid box. Both of these factors affect the lightning density. For two storm cells with equal lightning frequency, the storm cell moving more slowly will generate higher lightning density values. Finally, there is a tendency for greater lightning densities in the shorter-term products. This is because the 2-min product captures short-term variability, including large spikes in lightning activity. For the longer time increments, the lightning density product tends to average out the short-term fluctuations.

The training "quick guide" has two sides, with information on the lightning density product and the detection capabilities of the GLD360. It was designed so that forecasters have a reference available at their desks if they have questions while using the product. It also helps guide future training efforts. Figure 1 illustrates the training guide, which is divided into two sections, 1) operational use and 2) data properties.



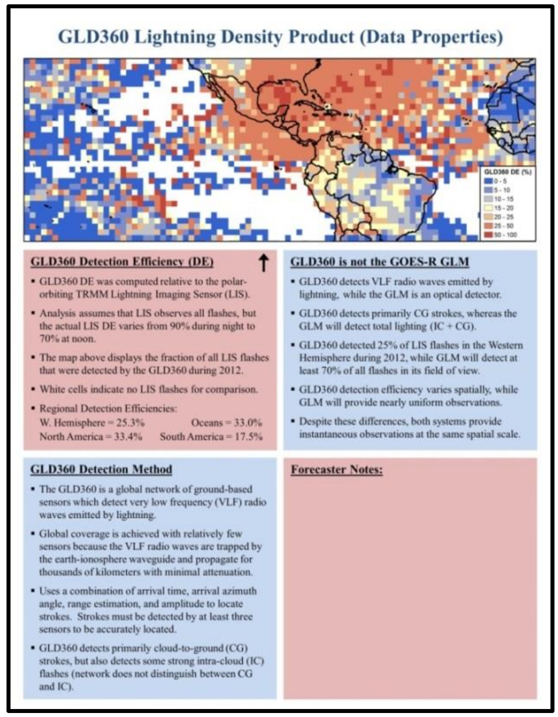


Fig. 1. Front (operational use) and back (data properties) sides of the training quick guide.

The operational use page contains a map of the 2012 GLD360 stroke count, showing the global distribution of lightning. An illustrated example shows a splitting supercell that is evident in the lightning density product, and there is a link to a website with animated examples. This operational use page also describes the method of calculating lightning density and offers suggested uses and product pairings. The data properties page includes a 2012 GLD360 DE map (Fig. 2), a description of the GLD360 lightning detection method and performance.

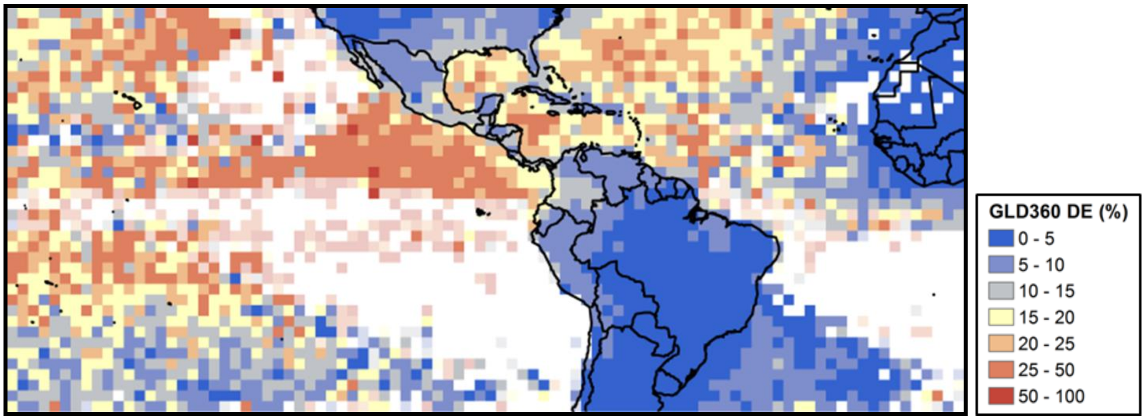


Fig. 2. 2012 GLD360 detection efficiency relative to the TRMM Lightning Imaging Sensor (LIS). Pixels with less than 15 LIS flashes are reduced in brightness and pixels with no LIS flashes are white. LIS detection efficiency is ~70% at local noon and ~90% at night.

The GLD360 also is compared to the GLM to describe their differences, and there is a section for forecaster notes regarding product use.

Shadowing forecasters allows us to observe the way they use the product and to gather informal feedback. Survey forms will be distributed to forecasters at the end of the demonstration period to collect additional information on the product and training. The combination of the introductory product presentation, the training guide as a reference, the lightning density product team shadowing forecasters, and the survey forms provides the forecasters an opportunity to gain familiarity with the product as the researchers observe how forecasters use the product. The following section elaborates on forecaster use of the product.

4. RESULTS

The improvement of the GLD360 lightning density product over the legacy product is evident in Fig. 3.

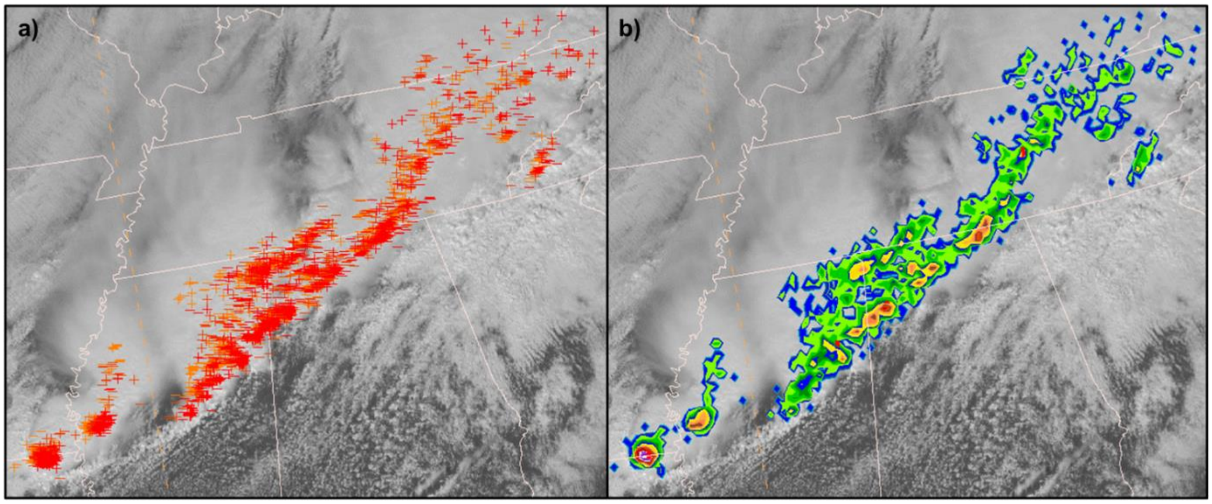


Fig. 3. GLD360 a) legacy stroke location product with a '+' or '-' to indicate polarity, and b) lightning density product with the strokes assigned to an 8 km x 8 km grid and the frequency calculated for each grid box.

The stroke location map shows many areas with enough lightning activity to stack the '+' and '-' symbols, making it difficult to determine where the most lightning is occurring. Local maxima in lightning activity are clearly evident in the GLD360 lightning density product. The display is very similar to the anticipated GLM flash density product and at the same resolution. The key difference is the detection capabilities of the GLM versus the GLD360. The GLM will provide total lightning observations with a higher, nearly uniform DE, whereas the IC detection by the GLD360 is extremely limited. For 2012, the GLD360 was found to detect 25% of TRMM/LIS flashes in the western hemisphere (using methods described by Rudlosky and Shea 2013; Fig. 2). The GLD360 DE varies spatially, but is fairly consistent over the eastern United States and the North Atlantic Ocean (the regions of primary concern for the OPC). Also, the GLM domain includes nearly the entire western hemisphere, and the GLD360 shows much greater DE variability in other portions of the western hemisphere (versus the North Atlantic Ocean).

Forecasters use the lightning density product regularly and find it to be a valuable tool. The lightning density product allows forecasters to observe convection beneath cold-cloud shields and locate convective maxima within larger features. Forecasters most often pair the lightning density product with infrared imagery. One forecaster found the product helpful for observing trends in lightning activity to evaluate strengthening or weakening convection, and noted that this was significantly easier with the density product than with the legacy stroke location product. The lightning density product aids in evaluating convective mode (e.g., splitting supercells, bowing line segments), which represents an improvement over the more standard binary determination of convection. Forecasters also use the lightning data for other more focused applications, including model validation and decision-support (e.g., adjustment of local winds fields).

The GLD360 lightning density product helps forecasters adjust local wind fields. Determining winds over the ocean can be a challenge since there are very few weather stations and no radar coverage offshore. One forecaster uses the lightning density to identify squall lines, and then adjusts the wind forecast for the region downwind from the squall line. Before using the product, another forecaster noted that the scatterometer surface wind retrievals can be contaminated during rain because of the disruption to the ocean surface, and that the lightning density would be helpful in estimating the winds in these situations. We observed the forecaster use the lightning density in this situation on 18 July 2013 (Fig. 4).

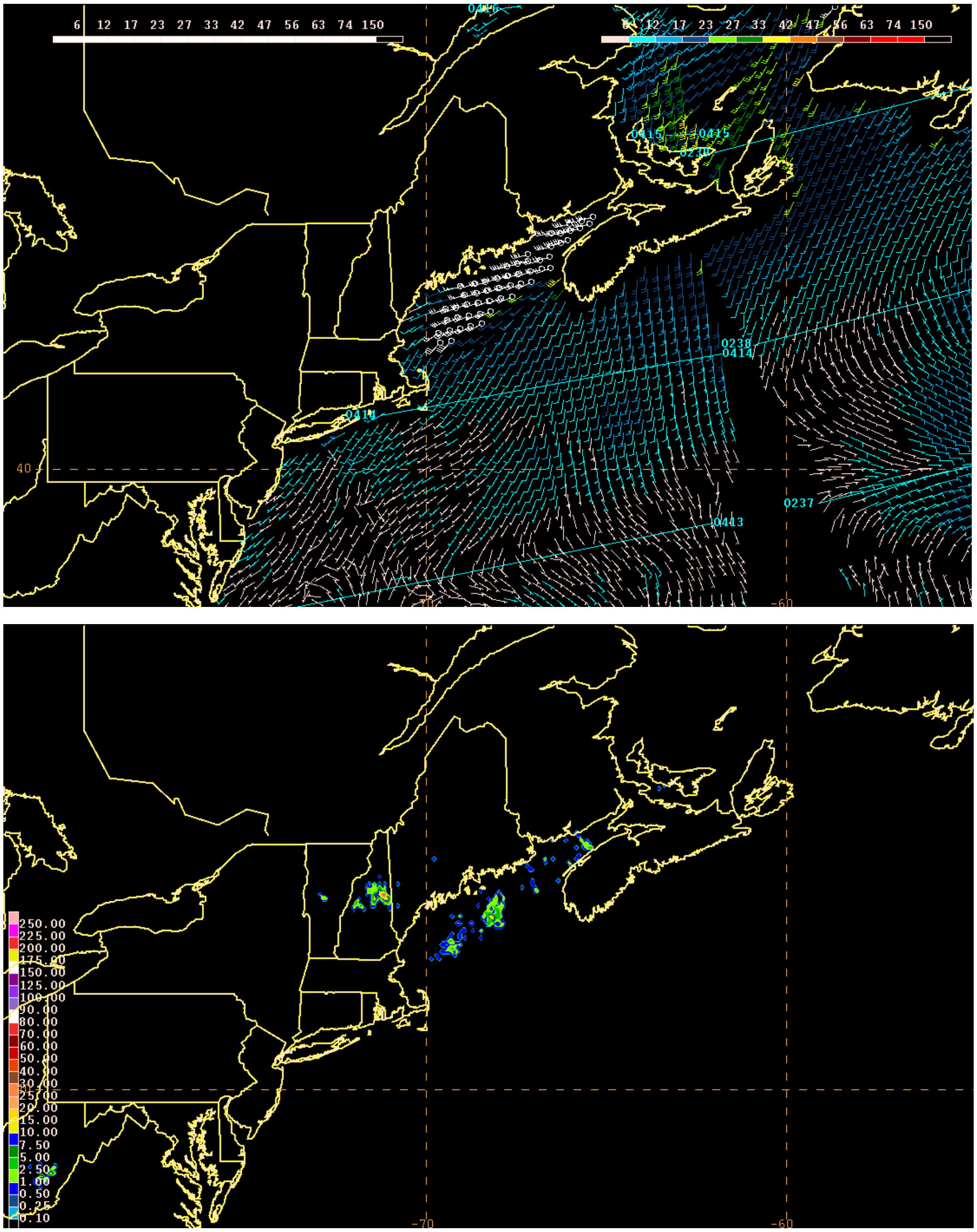


Fig. 4. Oceansat2 scatterometer winds at 0414 UTC (top panel) and GLD360 lightning density at 0415 UTC (bottom panel) on 18 July 2013.

The Oceansat2 scatterometer showed a large region of 50+ knot winds in the Gulf of Maine, but the retrievals were flagged as contaminated. To the east of this region, just off the western end of Nova Scotia, a smaller area of 35-40 knot scatterometer winds were not flagged. The model data populating the forecast grids showed no winds of that magnitude and no thunderstorms in the region. The lightning density product clearly showed the convection in the area, and gave the forecaster confidence in adjusting the wind forecast upward in this region.

Forecasters compare the lightning density with output from atmospheric models to evaluate whether the model accurately represents current conditions. This helps to gauge confidence in the future model predictions. The NWS SPC post-processes the Short Range Ensemble Forecast (SREF) output to create guidance tailored to thunderstorm and severe weather prediction. One such product is the 3-hour thunderstorm probability, which is based on the Cloud Physics Thunder Parameter, and calibrated using lightning data from the past 30 days (Bright et al. 2005, Bright and Grams 2009). It displays contours of the probability of a CG lightning strike within 15 miles for the 3-hour period ending at the forecast hour. At the request of the OPC, the SPC extended the domain of this product offshore into the Atlantic Ocean, and OPC forecasters use the product for guidance on where to expect storms moving offshore. Overlaying the 3-hour thunderstorm probability with the lightning density lets forecasters evaluate how well the 3-hour thunderstorm probability is locating active convection and to better diagnose future time periods (Fig. 5).

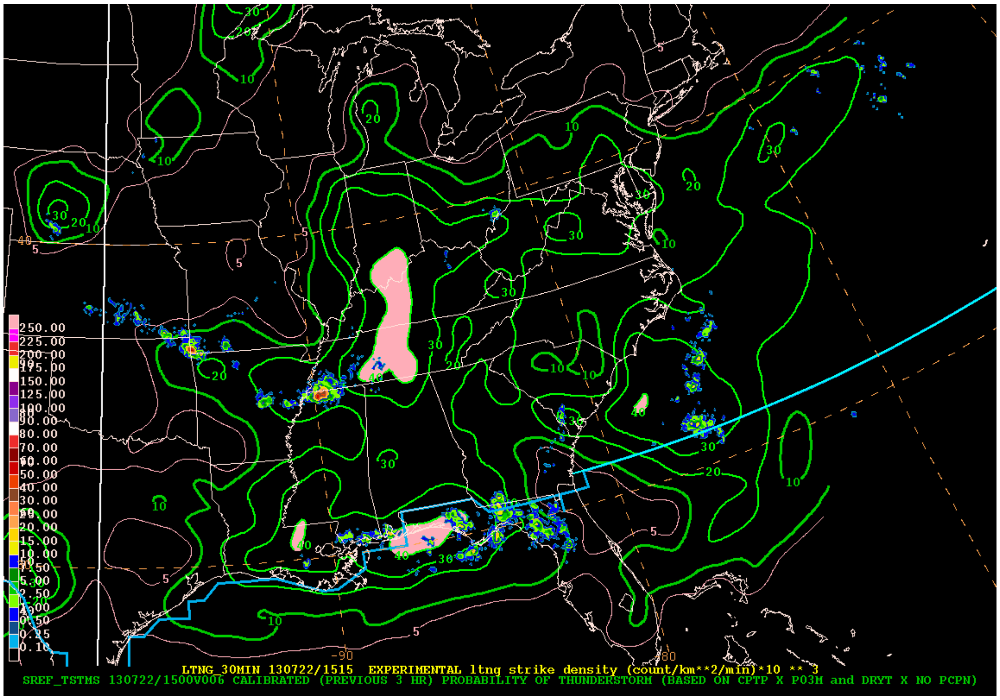


Fig. 5. SREF 3-hour Thunderstorm Probability (contours) and GLD360 30-min lightning density (shaded) at 1515 UTC on 22 July 2013.

Forecasters also compare the lightning density data with other model-derived fields.

In initial discussions, OPC forecasters felt the 15-min and 30-min density products would be most useful, but after using the product they found the 2-min and 5-min products more beneficial than initially anticipated. In particular, they found the short time-periods helpful for evaluating storms as they transitioned from land to the marine environment. It can be difficult for forecasters to determine if convection will continue as the storms move offshore. They can examine the Lifted Index (Galway, 1956) and other stability indices, but only model-derived fields since the oceans lack regular atmospheric soundings. Watching for short-term changes in lightning activity has proved helpful in this situation.

This project helps address the relative lack of information on the relationship between lightning and other storm parameters over oceans. In a study concurrent with the GLD360 lightning density demonstration, a U.S. Coast Guard intern at the OPC is examining the relationship between lightning density, overshooting tops, and other meteorological and oceanographical datasets over the ocean. The study looks at three major convective events that occurred partially over land and partially over ocean. Storm features are tracked at 15-min intervals based on the location of OTD-defined overshooting tops. At the location of each overshooting top, we document the frequency of lightning strokes, the OTD temperature difference, the sea surface temperature, and various other parameters. The study focuses on sustained convective features and changes during the transition from land to ocean. Information from this project and other future studies of lightning and storm characteristics over the ocean will help forecasters maximize the advantage of lightning data provided by the GLD360 and the future GLM.

5. CONCLUSION

A lightning density product was developed in collaboration between NOAA/NESDIS/STAR and the NWS OPC using the GLD360 lightning detection network. The project focused on preparing forecasters for the GOES-R GLM, improving OPC evaluation of offshore convection, and obtaining forecaster feedback to help improve the product and training. The GLM will provide continuous total lightning observations for nearly the entire western hemisphere at 8 km x 8 km resolution. Familiarizing forecasters with an ocean-basin scale lightning density product now prepares them to more easily integrate the GLM into future operations. It also has immediate benefits by providing forecasters with a valuable tool for evaluating offshore convection prior to GLM operations.

Forecasters at the OPC appreciate the lightning density product, and are now exploring different ways to use it. The product primarily is used to identify and quantitatively compare regions of lightning activity, but also to evaluate model output and adjust local wind fields. Forecasters at the OPC quickly gained familiarity with the product and immediately had ideas for ways to use. Forecaster feedback indicated that it is best to focus the lightning density training on the detection method and detection capabilities, as well as the details on how the product is obtained from the raw lightning data. Their feedback will be incorporated to further improve the lightning density product and training prior to wider distribution, and will be helpful for developing future GOES-R GLM training materials. Product pairings developed with the GLD360 lightning density product also will be beneficial for future GLM operations. The GLD360 lightning density product gives OPC forecasters a valuable tool for evaluating offshore convection and better prepares them for the GOES-R GLM era.

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