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Flow Regime Based Climatologies of Lightning Probabilities for Spaceports and Airports



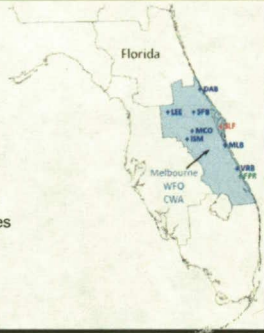
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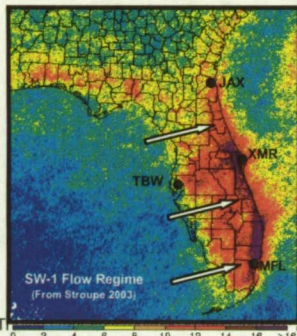
OBJECTIVES:

- Provide forecasters with a warm season climatological probability of one or more lightning strikes within a circle at a site within a specified time interval.
- Create climatologies based on Florida flow regimes for TAFs and shuttle landings for:
 - 9 sites
 - 5-, 10-, 20-, and 30-n mi circles around the sites
 - 1-, 3-, and 6-hour increments.
- Develop an easy to use GUI to display data.



FLOW REGIMES

- Studies at Florida State University (FSU) identified large-scale flow regimes over Florida, and found a strong relationship between the regimes and the spatial distribution of CG lightning across the peninsula (Lerico et al. 2002).
- The FSU studies yielded 7 distinct flow regimes.
- The average wind directions in the 1000 – 700 mb layer from the 1200 UTC soundings taken at Miami (MFL), Tampa (TBW), and Jacksonville (JAX) were used in combination to determine the flow regime of the day.



Flow Regime Name	Definition	Days in Regime
SW-1	Ridge from Atlantic High South of MFL	271
SW-2	Ridge from Atlantic High North of MFL and South of TBW	241
SE-1	Ridge from Atlantic High North of TBW and South of JAX	309
SE-2	Ridge from Atlantic High North of JAX	225
NE	Overall Northeast Flow	174
PAN	Ridge from Central Gulf Coast High over Panhandle	109
NW	Overall Northwest Flow	94
Other	Undefined Regime	827

- The sixth and seventh regimes account for general northwest and northeast flow across the peninsula.
- A flow regime could not be defined for a large percentage of the days in the study period, close to 40%. The AMU created an eighth category named 'Other' to account for these days.

ISSUES

- Needed to know:
 - Number of CG strikes in given period of time/distance from site
- Had to work with:
 - Code provided by FSU to read National Lightning Detection Network (NLDN) data in gridded format
- Needed to generate:
 - 1-, 3-, and 6-hourly grids for each day/each flow regime
 - 5-, 10-, 20- and 30- n mi circles for each site/each flow regime



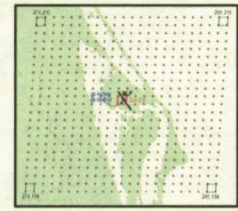
DATA

- The period of record (POR) was the warm season months of May – September in the years 1989 – 2004.
- All the data and code needed for development of the gridded climatologies was provided by FSU and NWS Tallahassee. The data included:
 - Lightning data grids created from NLDN data containing hourly CG strike counts in 2.5 x 2.5 km grid boxes. Grids encompass the entire state of Florida and adjacent waters.
 - Flow regime dates of occurrence for the POR.
- 1200 UTC soundings in the POR from MFL, TBW, and JAX; and 1000 UTC soundings from Cape Canaveral Air Force Station (XMR) for the sounding climatologies.
- The grids and soundings were stratified by flow regime prior to the creation of the climatologies.



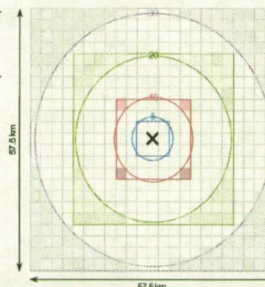
PROBLEMS

- Data
 - Gridded format not individual CG's
- Code designed for:
 - 24 hr intervals
 - Entire (rectangular) domain 954,281 km²
 - Not lat/lon based



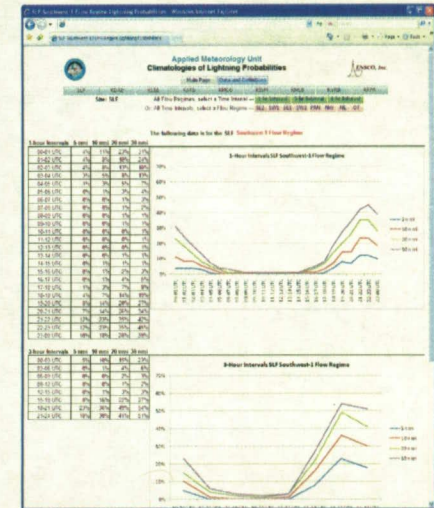
SOLUTIONS

- Data
 - No change
- Changed code
 - Multiple time intervals and smaller, multiple domains by lat/lon
- Used area of square instead of circle
 - 30-n mi circle:
 - o 529 grid boxes: area of square is 27% larger than area of circle
 - 20-n mi circle
 - o 225 grid boxes: area of square is 23% larger than area of circle
 - 10-n mi circle
 - o 49 grid boxes: area of square is 13% larger than area of the circle
 - 5-n mi circle
 - o 9 grid boxes: area of square is 16% smaller than area of the circle



USER FRIENDLY FORMAT

- Generated 864 spreadsheets in Excel® containing climatological probabilities of lightning for:
 - 9 sites
 - 3 time intervals
 - 4 different size circles
 - 8 flow regimes
- Merged the data from multiple spreadsheets into data tables grouped by time interval and flow regime
- Created graphs from the tables to provide a "quick look" tool for forecasters
- Built a GUI using HTML
 - Easily navigable web site
 - Platform independent
- Navigation
 - Data and Definitions
 - Nine sites
 - Flow regime or time interval
- Displays both tables and corresponding graphs



SUMMARY:

- Provided warm season climatological probability of one or more lightning strikes within a circle at a site within a specified time interval
 - Focus on Space Shuttle landings and NWS TAFs
 - Four circles around sites: 5, 10, 20 and 30 n mi
 - Three time intervals: 1 hr, 3 hr and 6 hr
- Based on:
 - NLDN gridded data
 - Flow regime
 - Warm season months of May-Sep for years 1989-2004
- Gridded data and available code → squares, not circles
- Over 850 spreadsheets converted into manageable user-friendly web-based GUI

WEBSITES AND REFERENCES

MLB Daily Lightning Threat Index Map: <http://www.srh.noaa.gov/mlb/gfw/lightning.shtml>
MLB IMPACT Meteorology Unit: http://www.srh.noaa.gov/mlb/amu_mlb/IMU2.html
Lightning Threat Graphic Descriptions: http://www.srh.noaa.gov/mlb/amu_mlb/TLG/tlgrcldmothreat.htm and http://www.srh.noaa.gov/mlb/gfw/lightning_levels.html
Applied Meteorology Unit: <http://science.bas.nasa.gov/amu/>
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FLOW REGIME BASED CLIMATOLOGIES OF LIGHTNING PROBABILITIES FOR SPACEPORTS AND AIRPORTS

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1. INTRODUCTION

The threat of lightning is a daily concern during the warm season in Florida. The forecasters at the Spaceflight Meteorology Group (SMG) in Houston, Texas produce lightning forecasts for the Space Shuttle Landing Facility (SLF) at Kennedy Space Center, Florida. Forecasters at the National Weather Service in Melbourne, Florida (NWS MLB) produce terminal aerodrome forecasts (TAFs) for seven airports (Daytona Beach, Orlando, Sanford, Melbourne, Vero Beach, Kissimmee and Leesburg) within their County Warning Area (CWA) in east-central Florida. Recent research has revealed distinct spatial and temporal distributions of lightning occurrence that are strongly influenced by large-scale atmospheric flow regimes. The objective of this work was to provide forecasters with a tool to indicate the warm season climatological probability of one or more lightning strikes within a circle at a site within a specified time interval.

2. BACKGROUND

In Phase I of this work, the Applied Meteorology Unit (AMU) (Bauman et al 2004) created 6- and 24-hour gridded cloud-to-ground (CG) lightning density and frequency climatologies based on the flow regime that the forecasters at NWS MLB use to issue daily lightning threat maps for their CWA (Lambert et al. 2006). Phase II of this work consisted of three parts. In the first part, the AMU created climatological soundings of wind speed, wind direction, temperature, and dew point at Miami (MFL), Tampa (TBW), Jacksonville (JAX) and Cape Canaveral (XMR), Florida for each of eight flow regimes from a 16-year database of soundings (Short 2006). In the second part, the AMU calculated the same climatologies as in

Phase I for the two 12-hour periods 0000–1200 UTC and 1200–2400 UTC. In the third part described in this paper, the AMU created flow regime climatologies for 5-, 10-, 20-, and 30-n mi circles centered on eight sites in 1-, 3-, and 6-hour increments. The 5- and 10-n mi circles are consistent with the aviation forecast requirements at NWS MLB. The 20- and 30-n mi circles at the SLF will assist SMG in making forecasts for violations of lightning occurrence during a space shuttle landing. The site locations for which the climatologies were created are shown in Figure 1 with their 5-, 10-, 20-, and 30-n mi circles.

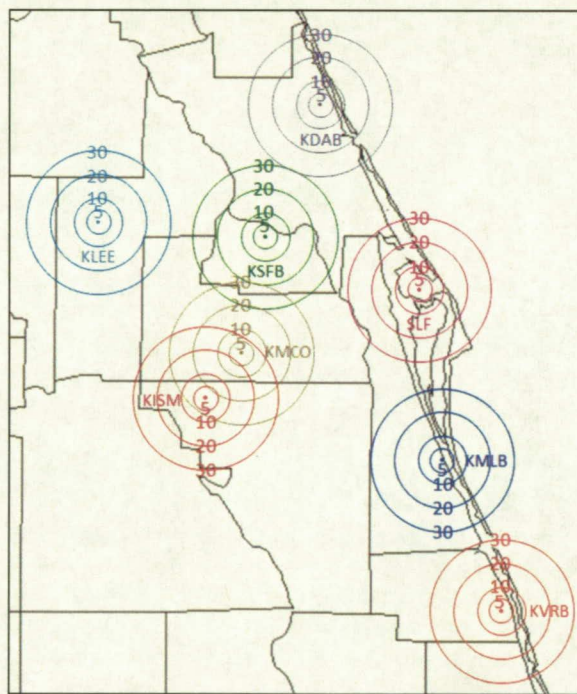


Figure 1. Map of east-central Florida showing locations of the SLF and seven airports. The circles around each location indicate the distance from the center of each site from 5 to 30 n mi.

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3. METHODOLOGY

Code from Phase I of this work was modified to determine the indices of the grid boxes to approximate the 5-, 10-, 20- and 30- n mi circles centered on the SLF and the other airports. The modified code created one value for the total number of lightning strikes in each circle based on the sum of the number of lightning strikes in all the boxes within the area of each circle. The lightning climatology calculations for an area otherwise remained the same. Instead of a value for each grid box as in Lambert et al. (2006), one value each for the probability of lightning occurrence and the mean number of strikes per flow regime was created for each circle. The resulting values included 1-, 3- and 6-hour climatologies in the 5-, 10-, 20- and 30 n mi circles for each of eight Florida flow regimes (Lericos et al. 2002; Lambert and Wheeler 2005).

3.1. Data and Period of Record

The NWS in Tallahassee, Florida provided National Lightning Detection Network (NLDN) (Cummins et al. 1998) gridded data of CG lightning strikes in a 405 x 377 grid covering all of Florida and surrounding the area as shown in Figure 2. The data had a spatial resolution of 2.5 x 2.5 km and a temporal resolution of 1 hour. The period of record (POR) for the data was the warm season months of May – Sep in the 16-year period 1989 – 2004.

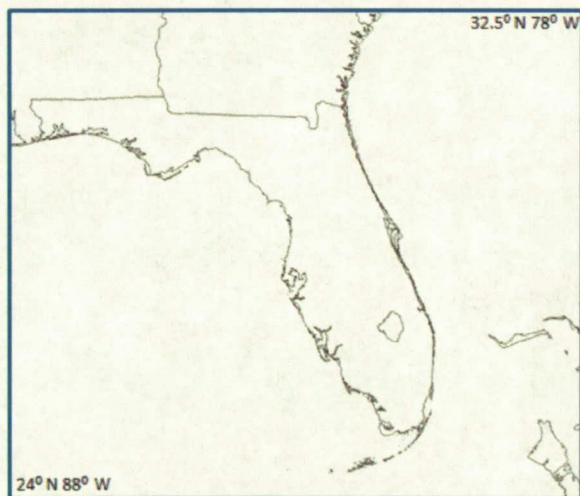


Figure 2. Domain of 405 x 377 2.5 x 2.5 km grid boxes of lightning data. The latitude and longitude of the southwest and northeast corners are shown.

3.2. Flow Regime Definitions

Florida State University (FSU) identified large-scale flow regimes over Florida and found a strong

relationship between the regimes and spatial distribution of CG lightning (Lericos et al. 2002). The flow regimes were based on the average wind directions in the 1000 – 700 mb layer from the 1200 UTC soundings at MFL, TBW and JAX. The studies yielded seven distinct flow regimes as shown in Table 1. Almost 37% of the days in the period could not be classified and are described as an eighth "Undefined Regime". Examples and detailed descriptions of the flow regimes can be found on the NWS MLB web page at the URL http://www.srh.noaa.gov/mlb/amu_mlb/LTG/ltgclimothreat.htm.

Flow Regime Name	Definition	Days in Regime
SW-1	Ridge from Atlantic High South of MFL	271
SW-2	Ridge from Atlantic High North of MFL and South of TBW	241
SE-1	Ridge from Atlantic High North of TBW and South of JAX	309
SE-2	Ridge from Atlantic High North of JAX	225
NE	Overall Northeast Flow	174
PAN	Ridge from Central Gulf Coast High over Panhandle	109
NW	Overall Northwest Flow	94
Other	Undefined Regime	827

Table 1. Definitions of the seven flow regimes and the number of days in each regime from the POR.

3.3. Challenges

The forecasters needed to know the number of CG strikes in a given period of time and specific distance from each site. If the data were available as latitude and longitude of individual CG strikes instead of gridded form it would have been easier to manipulate the data for the desired results. Additionally, the baseline code capable of reading the NLDN data in gridded format was provided to the AMU by FSU but was not intended to produce the desired results for this work. Due to workload and time constraints, instead of undertaking a major rewrite of the FSU code, which was written to produce data at 24 hour intervals for the entire 954,281 km² gridded domain, it was modified just enough to generate 1-, 3-, and 6-hourly grids for each day and each flow regime and 5-, 10-, 20-

and 30-n mi circles for each site based on latitude and longitude within the large grid.

3.4. Solutions

Modifying the FSU code required careful rewriting of small sections of the code to produce a single probability for each of the four circles and three time intervals at each of the eight sites. It was simple to output three new time intervals based on the provided code, but it was difficult to transition from a grid domain to a latitude/longitude (lat/lon) domain. For example, to make sure the conversion from the gridded domain containing the lightning data in 2.5 x 2.5 km grid boxes to the lat/lon point nearest to the center of each runway was working properly, output from the modified code was verified graphically. The output was imported into ArcGIS software and the grids were plotted over a map as shown in Figure 3 using the SLF. The domain approximating a 30 n mi circle from the center of the SLF is 22 x 22 grid boxes. As Figure 3 shows, the nearest grid square to the center of the SLF runway at 28.6150N, 80.6945W is (284, 205). Since the FSU code was designed to output data as square grids, it was necessary to approximate each of the four circles at each site with a square as described in the next section.

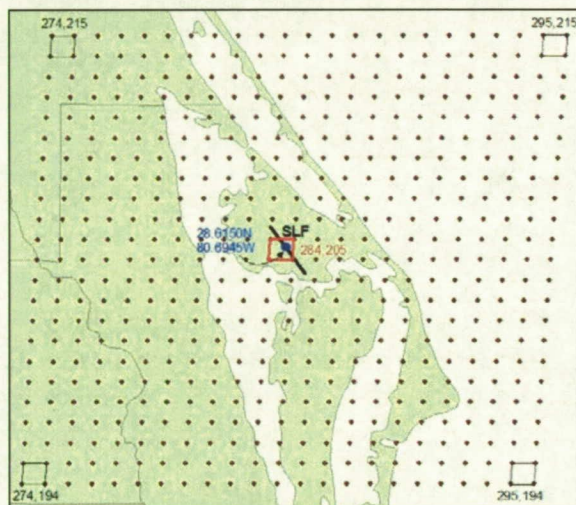


Figure 3. The 30 n mi grid with the SLF runway at the center. The four corners of the grid show the grid square coordinates (x, y). The red square is the grid box nearest the centers of the 30 n mi grid and SLF. The blue dot is at the lat/lon of the SLF runway center.

3.5. Approximating Circles with a Square Grid

Because the data were in the form of grid boxes instead of individual CG strikes, each of the circles was approximated by a square area around

each circle comprised of the grid boxes. Figure 4 shows the size of the four circles used in this work overlaid on a grid of 2.5 x 2.5 km grid boxes. This figure represents an idealized case where the center of a runway is at the middle of the range rings. The 5 n mi circle (blue) is represented by nine grid boxes (blue square). The area of the circle is 67 km² while the area of the square is 56.25 km². Thus, the area of the square is 16% smaller than the area of the 5 n mi circle. The 10 n mi circle (red) is approximated by 49 grid boxes (red square). Only four grid boxes (shaded in red) at the corners of the square are outside of this circle. The area of the square is 306 km². This is about 12% larger than the area of the circle, which is 269 km². The 20 n mi circle (green) is represented by 225 grid boxes (green square). There are 48 grid boxes (shaded in green) outside of the circle at the four corners of the square. The area of the circle is 1078 km² and the area of the square is 1406 km², or 23% larger than the circle. Finally, the 30 n mi circle (purple) is represented by 529 grid boxes (purple square). There are 144 grid boxes (shaded in purple) outside the circle at the corners of the square. The area of the circle is 2425 km² and the area of the square is 3306 km², or 27% larger than the area of the circle.

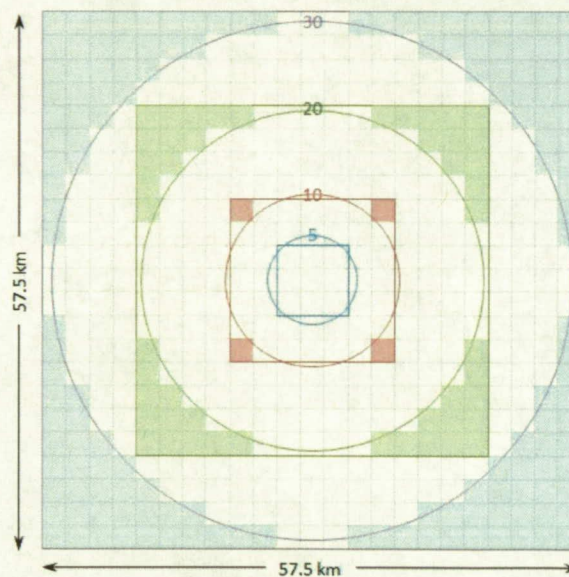


Figure 4. Depiction of the four circles and their idealized relationship to the 2.5 x 2.5 km grid boxes containing the lightning data. The 5 n mi circle is blue, the 10 n mi circle is red, the 20 n mi circle is green, and the 30 n mi circle is purple. The shaded grid boxes show the areas outside of the circles that were included in the computation of lightning probabilities.

In summary, using grid boxes to approximate the area of the circles likely resulted in climatological probability values that were too low for the 5 n mi circle and too high for the 10-, 20- and 30- n mi circles. Although the magnitude of the uncertainty is unknown for all four circles, one can assume that an over-estimate for the outer three circles would provide a more conservative estimate of lightning probability. An accurate way to create these values would be to use raw lightning data containing the lat/lon of each strike. As mentioned previously, data in that form were not available for this work.

3.6. Graphical User Interface

The output from the code was imported into Excel spreadsheets to create data tables and graphics for incorporation into a Graphical User Interface (GUI) that could be used operationally. AMU customers approved a GUI written in Hypertext Markup Language (HTML) because it is portable among different computer systems and intuitive to use in its similarity to a web browser.

The main page of the GUI is shown in Figure 5. From the navigation menu at the top of the page, forecasters can view the *Data and Definitions* page, which contains helpful information regarding the data, methodology and

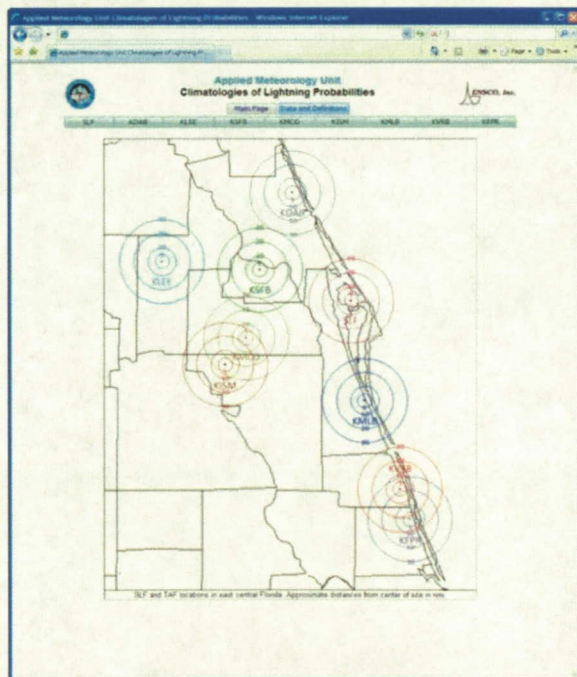


Figure 5. The main page of the GUI provides access to help information and a link to each site via a main navigation menu shown above the map or by clicking on the site on the map.

flow regime definitions, or they can click on a specific site in the navigation menu or the map. Once they have chosen a site, the main page for that site is shown, as for the SLF in Figure 6. The forecasters are presented with two sub-menus on the site page allowing them to view the lightning probabilities based on time interval (1-, 3- or 6-hours) or by flow regime. The main navigation menu remains visible so they can easily switch to another site or access the *Data and Definitions* page. An example of a time interval page is shown in Figure 7. These are the 3-hour climatologies for all eight flow regimes in all four circles centered on the SLF. The values are in a table on the left side of the page with a corresponding graph to the right of the table. The table/graph combinations represent the climatological values for each of the flow regimes. The 1- and 6-hour pages (not shown) have the same format.

An example of the flow regime page is shown in Figure 8. These are the Southwest-2 flow regime climatologies for all three time intervals in all four circles centered on the SLF. As in the time interval pages, there is a table on the left side of the page with a corresponding line graph to the right of the table. Data for all three time intervals for one flow regime is shown on this page.

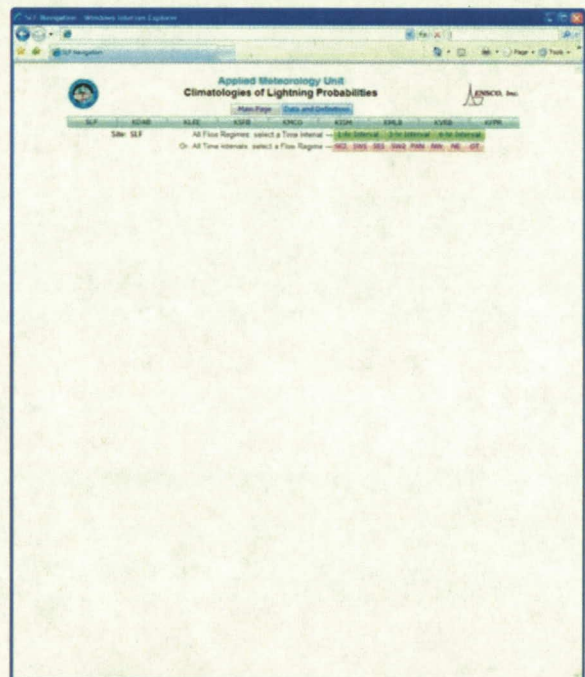


Figure 6. The main page for the SLF site. The two sub-menus allow the forecaster to view the data by time interval or flow regime.

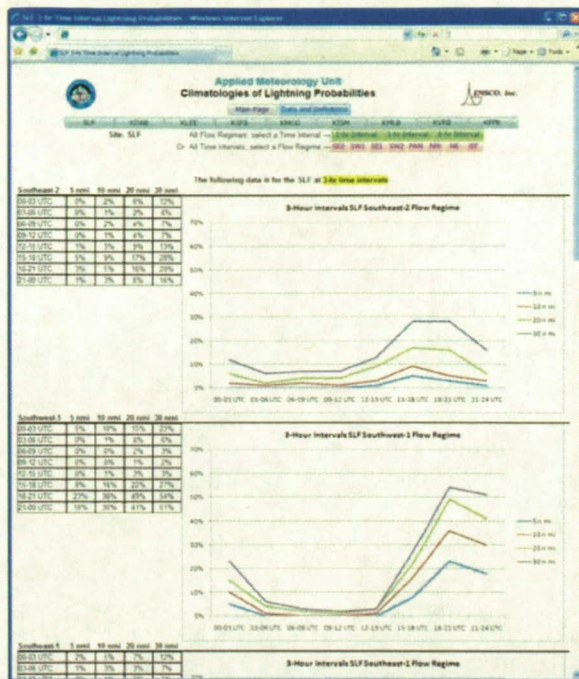


Figure 7. The SLF 3-hour interval data page. Tabular data is on the left with corresponding graphs to the right.

4. SUMMARY

The objective of this work was to provide forecasters with a tool to indicate the warm season climatological probability of one or more lightning strikes within a circle at a site within a specified time interval. This paper described the AMU work conducted in developing flow regime based climatologies of lightning probabilities for the SLF and seven airports in the NWS MLB CWA in east-central Florida. The paper also described the GUI developed by the AMU that is used to display the data for the operational forecasters. There were challenges working with gridded lightning data as well as the code that accompanied the gridded data. The AMU modified the provided code to be able to produce the climatologies of lightning probabilities based on eight flow regimes for 5-, 10-, 20-, and 30-n mi circles centered on eight sites in 1-, 3-, and 6-hour increments.

5. REFERENCES

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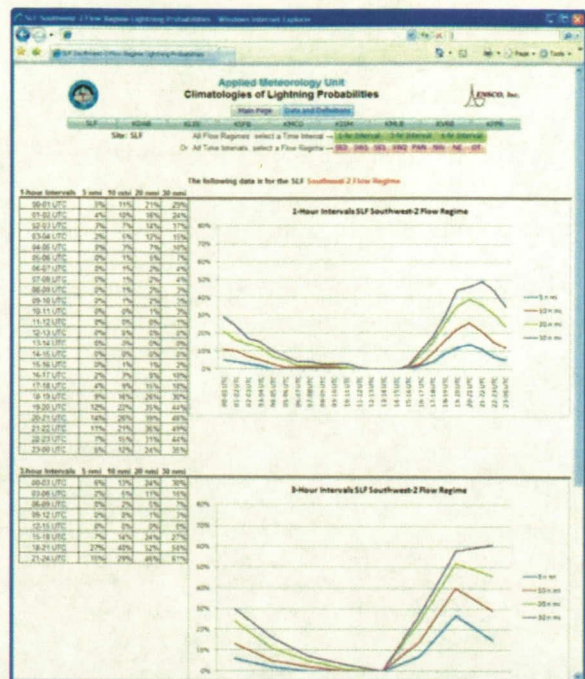


Figure 8. The SLF Southwest-2 flow regime data page. Tabular data is on the left with corresponding graphs to the right.

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