4.4 COMPARISONS OF CLOUD-TO-GROUND LIGHTNING FLASH DATA WITH NEXRAD INFERENCES ON RAINFALL AS FUNCTIONS OF LONGITUDE AND LATITUDE

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1. INTRODUCTION

Carbone et al. (2001a) recently reported on warm season U.S. climatology derived from analyses of NEXRAD radar reflectivity data that were interpreted in terms of rainfall intensities. Hovmöller diagrams (time-distance plots in time of day versus average values along longitude or latitude swaths) were used extensively to deduce climatological properties that were revealed through features evident on the plots. Their findings focused primarily on episodes, which were defined as time/space clusters of heavy precipitation that often result from sequences of organized convection such as squall lines, mesoscale convective systems and mesoscale convective complexes. Their results can be summarized as follows:

<u>Coherent rainfall events frequently (almost daily) occur over zonal spans of the order of 1,000 km for one-day durations.</u>

- Many of these events are of longer duration and larger in zonal extent than had previously been associated with mesocale. Convective systems, including mesoscale convective complexes.
- These occurrences appear to be compound events, consisting of a coherent succession of convective systems or “episodes.”
- Coherent dissipation and regeneration of convective rainfall within episodes were evident and were suggestive of a causal relationship among successive systems, including a suggestion of intrinsic predictability.
- The phase speed of the episodes was found to be greater than the phase speed of upper tropospheric anomalies and often exceeded zonal steering winds in the low- to mid-troposphere. (These characteristics were considered suggestive of a convectively–generated, wave-like propagation mechanism to explain the phenomena.)
    - The steering level was not found to be highly correlated with wind speed.
    - A significant fraction of episodes exhibits phase-locked diurnal behavior, consistent with thermal and topographical forcing.
    - The principal phase-locked signals appear to be diurnal forcing over the eastern and western cordilleras and semi-diurnal forcing between the cordilleras.

Since lightning is a significant feature of convective weather phenomena, it is of interest to determine the degree to which lightning data agrees with Hovmöller diagrams derived from NEXRAD measurements as used by Carbone et al. in the aforementioned climatological study. This paper examines this premise through an analysis of lightning data obtained from the National Lightning Detection Network (NLDN) operated by Global Atmospheric, Inc. (GAI). The NLDN detects and reports the occurrence of cloud-to-ground lightning flashes throughout the contiguous U.S. (Orville, 1991; Orville and Silver, 1997; Orville and Huffines, 1999; Orville and Huffines, 2001). The expectation is that the correlation between results derived from radar reflectivity measurements and those derived from lightning flash density counts should be very high, particularly when rainfall producing radar measurements are associated with thunderstorm/electrification producing convection. The results presented here confirm this expectation and reinforce the value of the type of analyses performed by Carbone et al. for both climatological insights as well as for suggesting ways of improving forecasting and nowcasting of precipitation and convective weather. Essentially, many of their conclusions could have been gleaned from NLDN data rather than from radar data. Also, combining both data sets provides important additional insights that are not possible from any one of the data sets alone. The latter is particularly important for discriminating between convective and non-convective or stratiform precipitation events as well as between precipitation and non-precipitation events that produce significant electrification and result in lightning activity in the absence of precipitation on the ground (e.g., virga, anvil events).

2. LIGHTNING DATA

The U.S. DOT Volpe Center has utilized and analyzed NLDN data for over 10 years, primarily in support of the FAA’s program to automate the detection and reporting of thunderstorms through Automated Weather Observing Systems (AWOS) and Automated Surface Observing Systems (ASOS) (Canniff, 1993; Kraus and Canniff, 1995; Kraus et al., 2000; Seliga et al., 2000). Essentially, NLDN data signify the occurrence of cloud-to-ground lightning flashes and represent the occurrence of thunderstorms throughout the U.S. The data have proven useful for numerous applications (e.g.,

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see Changnon, 1988a,b; Holle and Lopez, 1993; Orville, 1997; Orville et al., 1999; Rhoda and Pawlak, 1999; Seliga and Shorter, 2000; Orville and Huffines, 2001; Bates et al., 2001).

The NLDN flash data used here were for the years 1997 and 1998. The 1997 data were taken from the GAI archive, and the 1998 data were taken from Volpe Center NLDN records. The data sets consist of both negative and positive cloud-to-ground flashes.

3. METHODOLOGY

The lightning data were analyzed using Hovmöller diagrams, similar to those generated by Carbone et al. (2001a). These are diagrams with time plotted on the vertical axis and latitude or longitude on the horizontal axis. The time scales can range from a few days to a few months. Such diagrams have been found useful for climatological studies that examine one or more variables such as rainfall, temperature and winds. A sample Hovmöller diagram, produced from NLDN data for the period July 10-14, 1997 over the latitude range form 30-48^{o} N and extending over longitudes from 78-115^{o} W, is shown in Fig. 1.

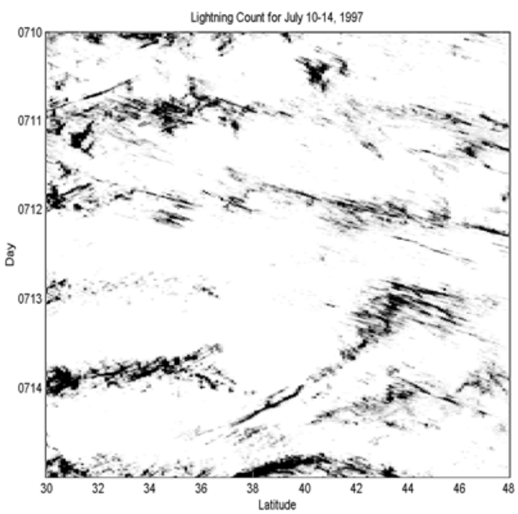

Fig. 1. Sample Hovmöller diagram of average lightning flash counts versus latitude for the period July 10-14, 1997. Time runs from the top down; the longitude extends from78-115^{o} W.

A thorough interpretation of the data in Fig. 1 requires additional insights; these might include reference to the corresponding Hovmöller diagram versus longitude, representations of the geographical distribution of the data at select sampling time intervals, referral to satellite data, knowledge of other meteorological parameters throughout the same spatial and temporal domains and representations of weather from applicable numerical models. Nevertheless, the data in Fig. 1 by itself reveals a number of important features. There is a distinct diurnal pattern in the lightning events with events repeating themselves daily, centered approximately around 1800 GMT extending between around 30-38^{o} on 7/13-14 and extending nearly over all the latitudes on 7/10-12 and 7/15.

Another generic set of features in Fig. 1 is the evidence of storm motion, ranging from stationarity to cell movements of various speeds in both S to N and N to S directions. The speeds of the motion are readily determined from the slopes of the streaks; these speeds can vary considerably while also at times exhibiting strong coherency from day to day, at certain latitudes and at certain times of the day. Special events are also immediately evident, such as the diurnal structures at northern latitudes that transition from S to N movement on 7/11-12 to N to S movement on 7/13-14.

Intensity is also of fundamental interest. The intensity in Fig. 1 represents the number of flashes occurring in 0.1^{o} latitudinal swaths over 15 min time intervals. Clearly, convective strength generally increases with this intensity. For example, the diurnal variability in storm occurrences evident at lower latitudes, mentioned previously, exhibits a significant decay in lightning activity from 7/11 to 7/13, followed by a re-intensification of activity on 7/14 and 7/15.

Fig. 2 is a gray scale reproduction of the same period Hovmöller diagram produced by Carbone et al. (2001b).

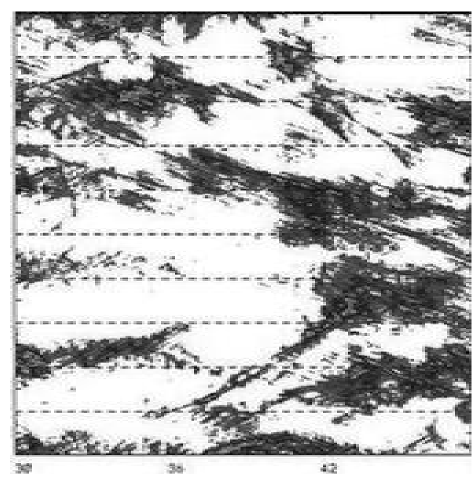

Fig. 2. Hovmöller diagram for the same period in Fig. 1, based on NEXRAD reflectivity data as analyzed by Carbone et al. (2001b). Note the very strong similarities in the two diagrams. Also, the gray scales are not representative of intensity.

This diagram is derived with a latitudinal resolution of 0.05 deg and time samples of 15 min (~ 3 NEXRAD samples, since the typical radar volume sampling rate is 5 min). The Hovmöller diagram of NLDN data in Fig. 1 compares very favorably with their radar-based results The most important and apparent conclusion form this comparison is the gross similarity (high qualitative correlation) of the diagrams, implying a strong relationship between lightning and rainfall in this instance. The radar-based diagram generally appears more diffuse compared to the lightning-based diagram. This is attributed in part to rainfall occurring at the edges of convective cells where lightning activity is less likely to occur. There are also regions where lightning is evident with very little if any radar-detected rainfall. The precise nature of these disparities is not known and deserves attention in future studies.

4. SELECT COMPARISONS

In order to further compare Hovmöller diagrams, one of Carbone et al.'s practical examples is examined here, namely, the 27-29 May 1998 episode covering the South Central U.S., extending from New Mexico to the pan handle of Florida in longitude (85-105^o W) and 30-38^o in latitude. Carbone et al.'s results are given in Fig. 3, and the results based on NLDN data are in Fig. 4.

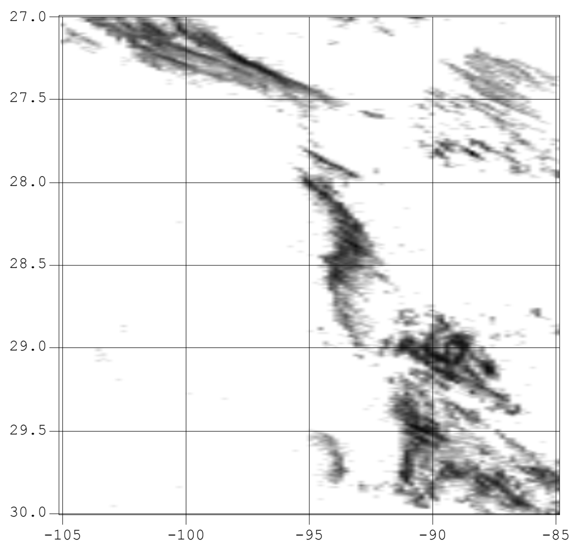

Fig. 3. Gray scale depiction of the 27-29 May 1998 episode, derived from the results of Carbone et al. (2001a). The abscissa is longitude and the ordinate is the date.

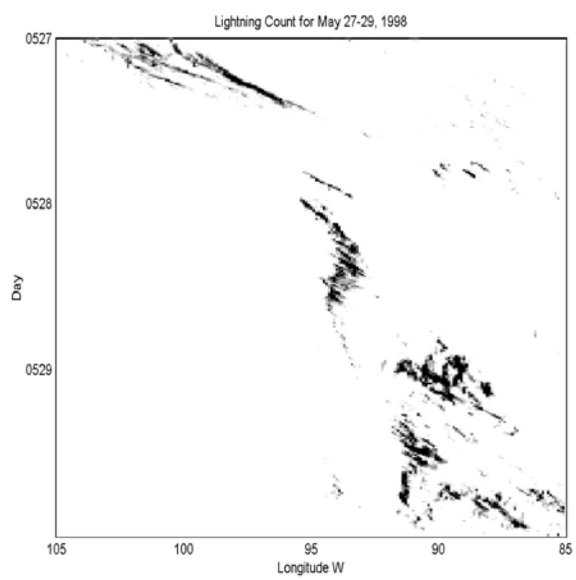

Fig. 4. Gray scale depiction of the 27-29 May 1998 episode from NLDN lightning data.

Similar to the latitudinal example in the previous section, there is excellent qualitative agreement in the features of both diagrams. Again, the radar diagram appears more diffuse, most likely associated with the existence of rainfall regions outside the main areas of convection. Practically all the fine-line features are present in both Hovmöller diagrams, demonstrating that the primary interpretations made by Carbone et al. would also be possible from lightning only data. Of possible interest are numerous fine details of the comparisons. For example, the relative intensities of the diagrams appear to differ, depending on the region and storm intensity. Overall, a numerical two-dimensional correlation coefficient between the radar-derived rainfall intensities and lightning counts was around 0.7, confirming the qualitative assessment inherent in a visual comparison between the diagrams. The underlying meteorological forcing conditions associated with both similar and disparate properties of both diagrams would be particularly interesting. Such studies should help determine the value of such investigations for better understanding of storm evolution and forecasting.

Another example of the importance of studying both radar and lightning data relates to the study of differences in precipitation type – convective versus stratiform. Convective storms are typically dominated by strong updrafts that combine with a complex array of ice and mixed phase hydrometeor processes to produce thunderstorms evidenced by numerous lightning discharges (Houze, 1993; Solomon and Baker, 1998). Stratiform precipitation, on the other hand, are characterized by low vertical velocities and the generation of precipitation derived primarily from vapor deposition and ice particle aggregation processes that generally do not produce electrification sufficient to produce lightning. Hurricanes are particularly useful for such studies, since they often involve significant amounts of both convective and stratiform rainfall types.

Figs. 5 and 6 are longitudinal Hovmöller diagrams of Hurricane Earl covering the period 3-7 Sept 1998 (http://www.nhc.noaa.gov/pastall.html). The official record of the hurricane track shows that the eye was at a longitude of around 87^o W when it entered the diagram at 9/3 at approximately 0000 GMT. It then transited from W to E with a nearly constant speed of ~ 0.063^o h^{-1} and exited the region of the diagrams around 0800 GMT on 9/4. The hurricane quickly weakened to a tropical disturbance around this time on the 4th. Fig. 5, taken from Carbone et al. (2001b), shows that moderate to heavy amounts of rainfall were associated with this hurricane and that this precipitation was primarily east (and north, although not shown here) of the eye track. Fig. 6, on the other hand, derived from lightning data, shows that very little lightning was associated with Earl in the heavy precipitation region. This is clear evidence that the dominant precipitation processes were stratiform, with small but sufficient amounts of electrification present to produce some cloud-to-ground lightning. Other hurricanes that transited the spatial domain analyzed by Carbone et al. (2000a) during 1997 and 1998 were also examined with similar results, namely, precipitation associated with hurricanes and their remnant regions of atmospheric disturbance appears to be primarily stratiform in type, since there was little evidence of any significant lightning activity associated with the hurricanes' precipitation fields.

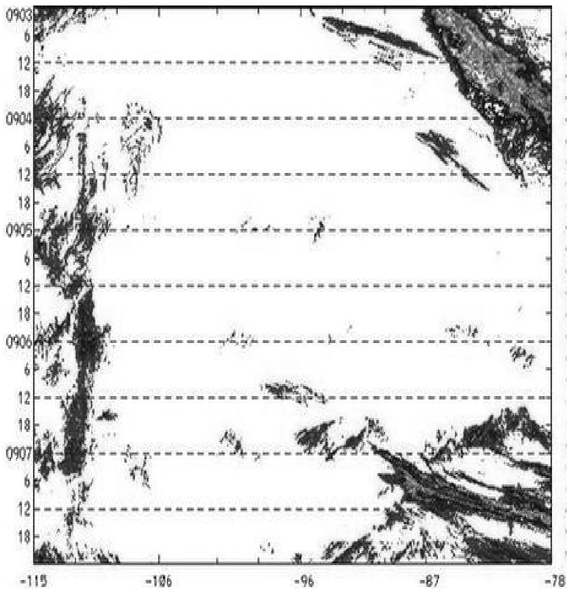

Fig. 5. Carbone et al. (2000b) longitudinal Hovmöller diagram for 3-7 September 1998, showing the rainfall due to the transit of Hurricane Earl in the upper right hand corner.

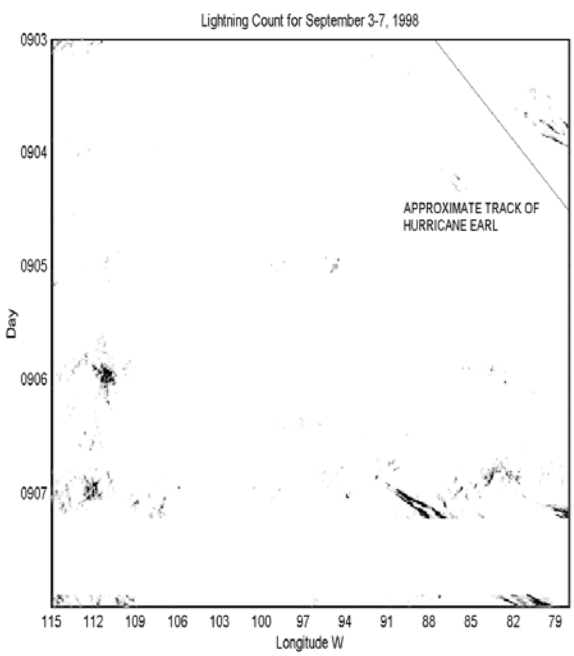

Fig. 6. Lightning-based longitudinal Hovmöller diagram for 3-7 September 1998, showing the sparse amount of lightning activity associated with the passage of Hurricane Earl. Transit of the eye of the hurricane through the region is also shown.

5. SUMMARY

There is a generally high degree of correlation between NLDN flash density data and NEXRAD rainfall intensity. A number of differences were also noted:

1) Significant areas of rainfall with no NLDN flashes or few NLDN flashes were found. Some rain events do not have the moist convective conditions necessary for thunderstorm formation. This situation was strongly evident in Figs. 5 and 6 that show heavy widespread rainfall during the passage of Hurricane Earl along with little associated lightning activity.

2) There were a few instances of NLDN flashes but no rainfall in the sample data sets. Examples of these phenomena can be found in Figs. 1 and 2.

3) Diurnal patterns are more distinct on the NLDN plots than the rainfall plots as seen in Figs. 1 and 2.

Storm motions are also evident and correlated very well between both NLDN and NEXRAD Hovmöller plots in terms of zonal and meridional speeds

6. RECOMMENDATIONS

The results of this investigation clearly show that meteorological and climatological evidence derived from lightning data is comparable to insights obtained from NEXRAD radar data as represented in Hovmöller diagrams produced by Carbone et al. (2001a). Furthermore, differences in the two data sets appear useful for gleaning additional insights into the properties and forecastability of significant weather events throughout the contiguous U.S. In addition to improving the overall understanding of storms, studies of this type should help improve the forecasting of severe weather for public safety applications. They should also lead to improved aviation operations through better planning and operational practices that depend on reliable weather observations and forecasts.

The analyses presented here and by Carbone et al. (2000a) represent only a very small fraction of the science and operational potential resident in these data sets. It is also important to note that both data sets have limitations that are not discussed here. Regarding lightning data, considerably more information can be gotten from a total lightning detection and reporting system that includes intracloud as well as cloud-to-ground flash information. This is particularly true, since it is well known that the number of intracloud flashes greatly exceeds cloud-to-ground flashes and that a significant fraction of intracloud flashes often precedes the initiation of convective precipitation. This total lightning capability is available in other countries and should therefore be implemented in the U.S. in order to further the scientific and practical potential inherently present in such data.

7. REFERENCES

Bates, E. G., T. A. Seliga and T. Weyrauch, 2001: Implementation of grounding, bonding, shielding and power system improvements in FAA systems: Reliability assessments of the Terminal Doppler Weather Radar (TDWR). 20th Digital Avionics Systems Conference, Daytona Beach, FL, 14-18 October.

Canniff, J. F., 1993: Thunderstorm detection: FAA applications for network lightning data. Preprints 8th Symposium on Meteorological Observations and Instrumentation, AMS Annual Mtg., Anaheim, CA, 91-92.

Carbone, R. E., J. D. Tuttle, D. A. Ahijevych and S. B. Trier, 2001a: Inferences of predictability associated with warm season precipitation episodes, submitted *J. Atmos. Sci*., Jan. 2001.

Carbone, R. E., J. D. Tuttle, D. A. Ahijevych and S. B. Trier, 2001b: Website for charts and base data; http://www.mmm.ucar.edu/episodes/index.html.

Changnon, S. A., 1988a: Climatography of thunder events in the conterminous United States. Part I: Temporal aspects. *J. Climate*, vol. 1, 389-398.

Changnon, S. A., 1988b: Climatography of thunder events in the conterminous United States. Part II: Spatial aspects. *J. Climate*, vol. 1, 399-405.

Holle, R. L. and R. E. Lopez, 1993: Overview of real-time lightning detection systems and their meteorological uses. NOAA Tech. Memo. ERL NSSL-102, 68 pp.

Houze, R. A., Jr., 1993: *Cloud Dynamics*, Acad. Press, Inc., 573 pp.

Kraus, K. and J. Canniff, 1995: Incorporating lightning data into automated weather observations. Preprints 6th Conference on Aviation Weather Systems, AMS, 466-469.

Kraus, K., T. A. Seliga and J. R. Kranz, 2000: Final performance evaluation of the Automated Lightning Detection and Reporting System (ALDARS). Preprints 16th International Conference on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, Long Beach, CA, AMS Annual Mtg., 106-109.

Orville, R. E., 1991: Lightning ground flash density in the contiguous United States – 1989. *Mon. Wea. Rev.*, **119**, 573-577.

Orville, R. E. and A. C. Silver, 1997: Lightning ground flash density in the contiguous United States – 1992-95. *Mon. Wea. Rev.*, **125**, 631-638.

Orville, R. E. and G. R. Huffines, 1999: Lightning ground flash measurements over the contiguous United States: 1995-97. *Mon. Wea. Rev.*, **127**, 2693-2703.

Orville, R. E. and G. R. Huffines, 2001: Cloud-to-ground lightning in the United States: NLDN results in the first decade,1989-98. *Mon. Wea. Rev.*, **129**, 1179-1193.

Rhoda, D. A. and M. L. Pawlak, 1999: An assessment of thunderstorm penetrations and deviations by commercial aircraft in the terminal area. MIT Lincoln Laboratory Project Rept., NASA/A-2, 98 pp.

Seliga, T. A. and J. A. Shorter, 2000: Contribution to a baseline understanding of the impact of weather on airline carrier operations, Preprints 2nd Symposium on Environmental Applications, AMS Annual Mtg., 9-14 January 2000, Long Beach, CA, 190-193.

Solomon, R. and M. Baker, 1998: Lightning flash rate and type in convective storms. *J. Geophys. Res.*, **103**, 14,041-14,057.

TPC NHC PAST HURRICANES (Tropical Prediction Center, National Hurricane Center) URL: http://www.nhc.noaa.gov/pastall.html