Integration of Lightning Detection Systems in a Modernized National Weather Service Office

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1. Introduction

In addition to the WSR 88D radar and high resolution satellite imagery, the forecasters at the National Weather Service office in Melbourne, Florida (NWS/MLB) have access to two types of real time lightning detection systems to assist them in preparing short term forecast and warnings. The first type of lightning system is the National Lightning Detection Network (NLDN), operated by the GDS corporation. At NWS/MLB, the NLDN system is set to detect all cloud to ground lightning (both positive and negative polarity) which occurs over the state of Florida and the surrounding coastal waters. The second type of lightning system, developed by NASA, is called Lightning Detection and Ranging (LDAR). This system detects volumetric lightning discharges in convective cells over east central Florida and the adjacent coastal waters.

2. Description of Lightning Systems

2.1 NLDN Lightning System

The NLDN lightning system is a more widely known lightning detection system which is in use at many locations across the United States. This system uses both the time of arrival and magnetic direction finding to locate cloud to ground lightning flashes (Holle et. al 1993). The detection efficiency of the NLDN system is approximately 80% (Orville - personal communication), and the accuracy is approximately 500 meters (Orville 1994). At NWS/MLB, the NLDN system displays cloud to ground lightning which occurs over the Florida Peninsula and adjacent coastal waters. This system also detects the polarity of each type of lightning flash, and keeps a running total of each type of flash.

2.2 LDAR Lightning System

The LDAR system was developed by NASA to give increased lead time to the overall lightning activity for lightning sensitive operations in the vicinity of the Kennedy Space Center (KSC). The system is unique in that it displays individual discharges or "points" of lightning in real time in a 3 dimensional (X,Y,Z) format. All types of lightning are detected by this system, including cloud to cloud, cloud to air, in cloud, as well as cloud to ground. A detailed description of how the LDAR system operates is given by Lennon (1991) with only a brief description given here.
The LDAR system detects lightning by using an array of 6 antennae, located at the KSC, to detect lightning induced "disturbances" at the 66 MHZ frequency. The system uses a time of arrival approach through the use of the extremely accurate Global Positioning System (GPS). The lightning discharges, which travel at the speed of electromagnetic radiation, arrive at the different antennae sites at slightly different times. The three dimensional position of the lightning discharge source is determined by converting these time offsets into distance differences, and then performing a triangulation.

In order to observe the 3 dimensional data on a 2 dimensional computer monitor, the LDAR display software "maps" the data so the operator can visualize in 3 dimensions. This is accomplished by first displaying the data points in a X-Y (planview) format. It then "projects" the data on an east-west vs altitude panel, and a north-south vs altitude panel. A total of 5 minutes worth of data are displayed at one time. A fourth panel displays a histogram, in one minute increments, of the data displayed within the planview panel. Figure 1 shows an example of the LDAR display.

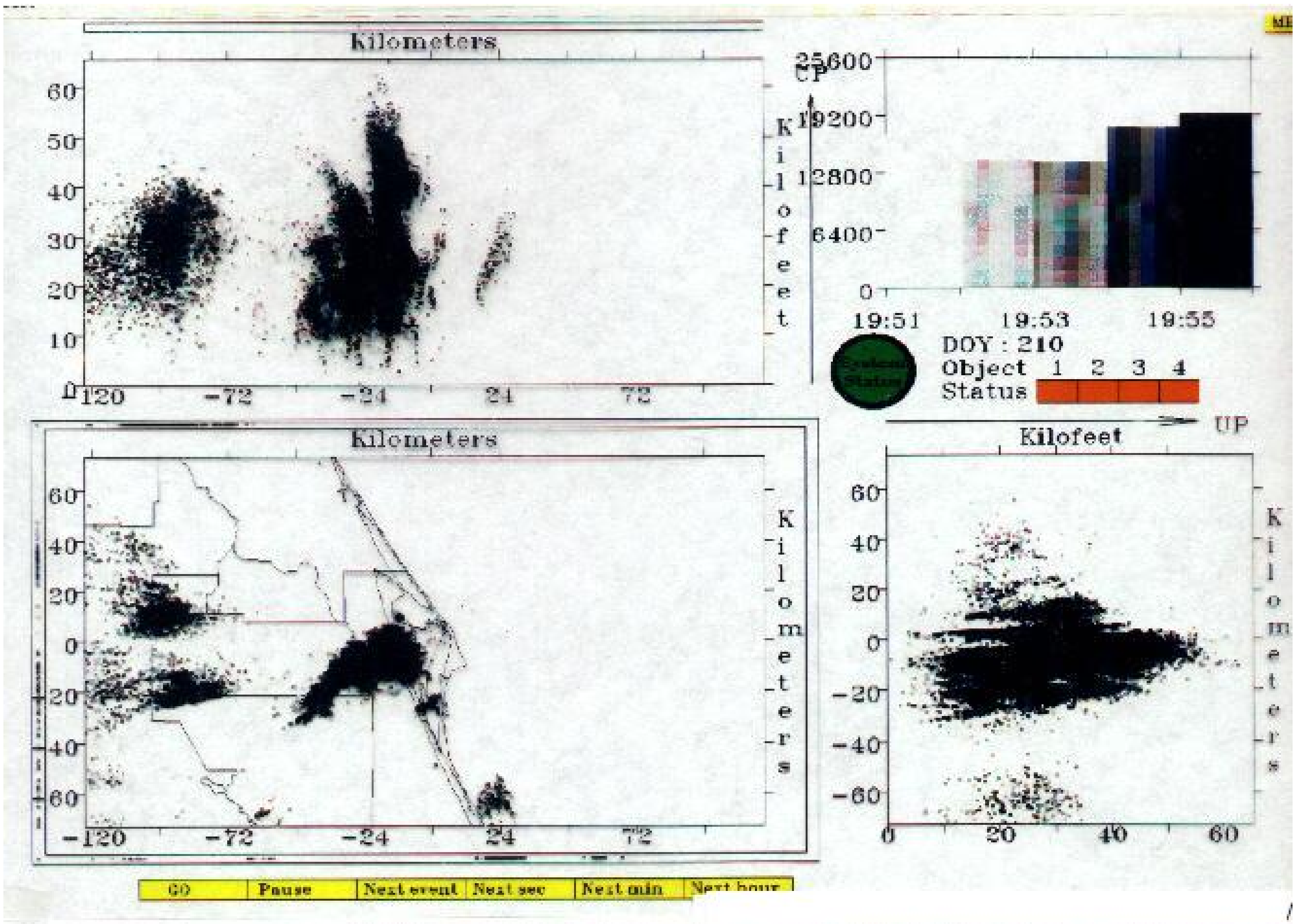

Fig. 1. The real time LDAR display. The lower left panel shows LDAR data on a map of Florida (partially shown). The data is then projected on an east-west vs altitude panel (upper left) and a north-south vs altitude panel (lower right. Note this panel is turned 90 degrees on its side). A histogram (upper right) displays the data in 5 one minute increments.

Forbes (1993) has shown that the accuracy of each lightning strike detected by LDAR is better than 300 meters within 20 km of the LDAR site. The bearing of each strike is 0.5 degrees regardless of range. It has been found that an individual lightning strike within a distance of 20 km can generate over 10 000 discharge points.

3. Operational Applications Using Both Lightning Systems.

Both the LDAR and NLDN display systems are located in the immediate forecast operations area at NWS/MLB. The forecast area consist of the WSR 88D Principal User Processor, the weather forecast and warning workstation, satellite imagery, communication computers and the lightning systems. With easy access to lightning data, forecasters have become experienced in its use, while integrating it with the other data sources for preparation of short term products.
The forecasters have found 5 distinct benefits associated with the NLDN and LDAR lightning systems. They are:
The lightning systems show when the atmosphere
is beginning to become electrically active.
Where the electrical activity is occurring.
How much electrical activity there is.
The trends in electrical activity.
When the electrical activity is dissipating.

3.1 Examples Of Operational Applications

Public

The peninsula of Florida is the lightning capital of the world. In east central Florida alone (NWS/MLB forecast/warning area), approximately 90 to 100 thunderstorm days occur each year, primarily in the summer months. With the lightning detection systems, the forecasters at NWS/MLB are able to track and monitor the trends and amount of lightning activity occurring over the forecast area. With this information, and the knowledge of local geography (beaches, lakes, major tourist areas, etc), the time of day (afternoon, nighttime), the day of the week (weekends, holidays), the forecaster has the capability to tailor short term forecast (NOW) to alert the public to the lightning threat.
An example of how the lightning systems can help the forecaster tailor the NOW for a specific area would be for a beach area during a major holiday weekend. During these times, the beach areas are likely to be at capacity with numerous residents and tourist alike. By observing the amount of lightning, trends in the lightning activity and information gleaned from the WSR-88D (such as the speed of movement and possible sea breeze interactions with the thunderstorms), the forecaster can prepare a NOW discussing the threat heading towards the beach area. The forecaster could also add brief safety rules for beach areas. An example of a short term forecast for a beach area would be:

"By 2 pm, a line of strong thunderstorms will approach the greater Daytona Beach area. Lightning detection systems indicated that deadly cloud to ground lightning was increasing with these storms. Some of these dangerous lightning flashes where striking the ground well ahead of the heavy rain. Beach-goers are urged to clear the area as the beach is a dangerous location to be at during a thunderstorm. Remember, an open beach shack offers no protection from a direct lightning strike. However, a closed automobile offers excellent protection during a lightning storm".

Marine

One of the greatest dangers to mariners is lightning. With the lightning systems, forecasters can monitor the trends and locations of electrically active cells over the east central Florida coastal waters and advise the marine community of where the most active weather is occurring. This information is especially critical when the peninsula is under westerly steering flow and storms initiate over the peninsula and move east over the Atlantic coastal waters. If the forecaster observes that lightning intense cells will be moving out over the coastal waters, a marine weather statement or special marine warning can be issued warning of the danger. In addition, once storms are occurring over the coastal waters, statements can be issued advising where the most intense lightning activity is occurring.

Site Specific

Short term forecasts required for site specific events are helped significantly by the lightning systems. One such event which occurs in east central Florida every year in July is the Special Olympics. Many of the sporting events associated with the Olympics are held outside, which exposes thousands of the handicapped participants and spectators to the potential lightning danger. When the Olympics are in progress, event coordinators request detailed short term forecasts. With the LDAR and NLDN systems, in conjunction with the WSR-88D and satellite imagery, the forecasters can advise the coordinators of the onset of cloud to ground activity, and/or the extent and location of the lightning activity which is occurring in the vicinity of the event.

Aviation

By comparing the two lightning systems, the forecaster can identify cells which are producing only in cloud lightning, or both in cloud and cloud to ground lightning. A storm that is producing only in cloud lightning would be displayed on the LDAR system (since it detects all types of lightning), but would not show up on the NLDN system. Knowing this information can be an advantage with respect to aviation nowcasting. During the dry season in Florida, there are times when the atmosphere becomes electrically active, but this activity remains in cloud, and likewise remains undetected by the NLDN system. An example of such an event occurred during the winter of 1994/95 over the central Florida peninsula. As this event evolved, the MLB forecaster, using the LDAR system, was able to advise the aviation forecaster of the electrical activity. Prior to notifying the aviation forecaster, no mention of thunderstorm activity was in the aviation forecast.

Local benefit

In addition to the benefits to the general public, the LDAR and NLDN systems have a direct benefit related to the operations of the weather office, as these systems allow the forecaster to see how close the lightning activity is relative to the office. If the activity gets within range close enough such that the office could be threatened by a lightning strike, the forecaster can change power from commercial to generator.

4. Additional Findings

4.1. Long Range Capacity Using LDAR

The National Weather Service is a collaborating partner in NASA's Applied Meteorological Unit (AMU). The AMU was created in 1991 as an interagency effort among NASA, the USAF at Patrick AFB and Kennedy Space Center, the National Weather Service in Melbourne and the National Weather

Service Space Meteorology Group at NASA's Johnson Space Center in Houston. The function of the AMU is to improve weather support for the space program and to enhance public weather forecasting and warning programs by means of technology transfer from this support to spaceflight operations. Typical interactions involving the AMU include participation in field projects, development of new forecasting techniques and evaluations of new technology. The LDAR system is an example of collaborative efforts between the organizations in evaluating new weather related technology.

By memorandum of understanding, NWS/MLB is responsible in evaluating the LDAR unit with regard to the following:

- Examination of LDAR associated with advisories and warning for east central Florida.
- Examination of long range (Central FloridaPeninsula scale) capabilities and applications of LDAR, including accuracy.
- Intercomparison of LDAR and NLDN data.

The first point above was discussed in section 3.1. The second and third points are discussed below.

As discussed in section 2.2, the LDAR system is very accurate close to the antennae site at the Kennedy Space Center. Farther out from this location, however, the overall accuracy of the LDAR unit is unknown. In the limited cases which have been collected and analyzed, the LDAR system has identified lightning discharges at significant distances from the LDAR site. Some locations in which lightning discharges have been detected include Jacksonville, the northwestern Florida peninsula, the Gulf of Mexico, southwest Florida, south Florida near and over Lake Okeechobee and over the Atlantic.

Overall, the LDAR can detect lightning discharges at distances beyond those found by Forbes (1993). However, the farther from the lightning is from the LDAR site the less amount of data is displayed. For significant distances, that is distances more than 100 miles away, only 2 or 4 LDAR points may be detected per lightning strike.

It was found that the LDAR signature becomes deformed with increasing distance from the central site. The deformation is most noticeable in the upper parts of the lightning flash, as this part of the flash will "azmuthally shear" away from the lower part of the flash.

Although exact values are not known at this time, it appears that for storms at significant distances, the LDAR system (when it detects the flash) will display data points very close to where the actual lightning flash (according to the NLDN data) occurred.

4.2 Examination of an Unique LDAR Lightning Signature

In addition to the operational applications of the LDAR system, the LDAR permits the forecasters to observe and analyze all types of lightning discharges. One type of discharge which is rather unique is a "bolt from the blue". To avoid confusion, a bolt from the blue is defined here as:

Lightning which comes out of the side of the updraft, travels a significant distance in the horizontal away from the parent updraft from which it originated, then turns down towards the ground and strikes the ground.

A bolt from the blue is different from "anvil lightning" in that anvil lightning originates from the anvil and typically travels straight down towards the ground.

A total of three cases of bolts from the blue have been either seen or documented using the LDAR unit. One of these cases was unknowingly documented by Forbes (1995 - Fig. 2). The second was documented by the author, using a 35 mm camera. The third case was witnessed (on the LDAR display) by the author during the summer of 1995, but was not documented on film. Of the two cases which were documented, the bolt from the blue originated from 7 to 9 kilometers AGL. The bolt then travelled horizontally on a slight downward angle for 7 to 8 km and then angled down and struck the ground. Of the two cases which were witnessed by the author, the strikes emanated from the opposite direction in which the storm was moving.

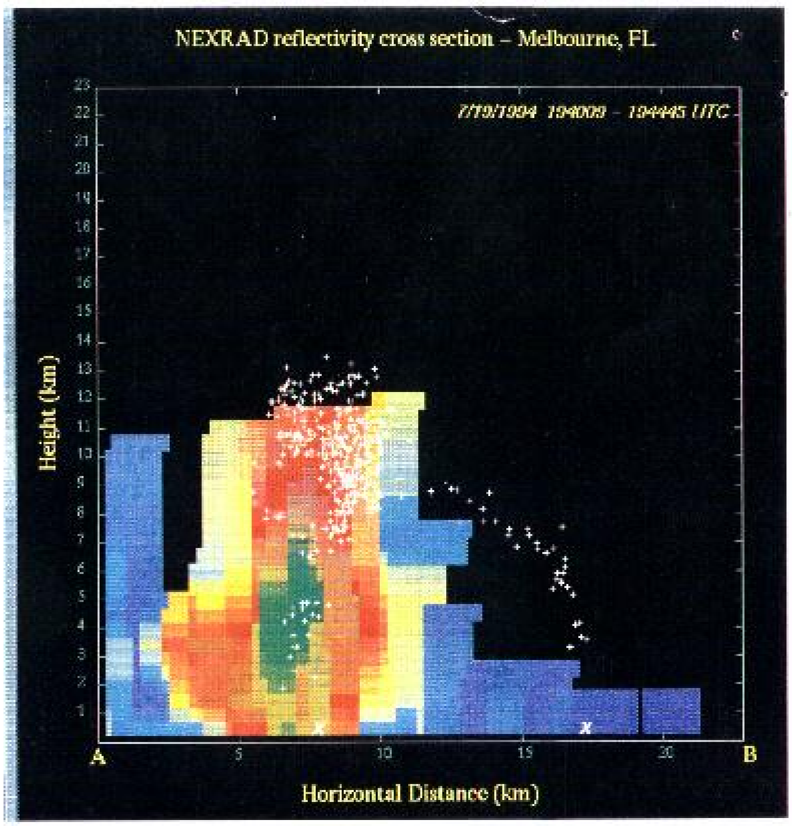

Fig. 2. LDAR data overlayed on KMLB WSR 88D reflectivity cross section. "Bolt from the blue" is shown emanating from the right side of updraft into clear air and then down to the ground. From Forbes (1995).

Holle et al. (1993), found people in Florida were more likely to be victims of lightning strikes at the end of the storm, rather then at the beginning, or during the storm. It was surmised that this was likely due to people resuming outdoor activities too soon after the storm had ended. Bolts from the blue can be very dangerous in this regard since they appear, from the publics point of view, to strike well after the storm has passed.

Intense Cloud to Ground Lightning Activity

All thunderstorms, by definition, produce lightning. However, There are days when the lightning activity over the peninsula is significantly more intense than others. Cloud to ground lightning flash rates exceeding 500 flashes in 30 minute over a relatively small area (such as part of a county) have been documented with the NLDN system (Fig. 3). This poses a question to what is the cause of this intense lightning activity.

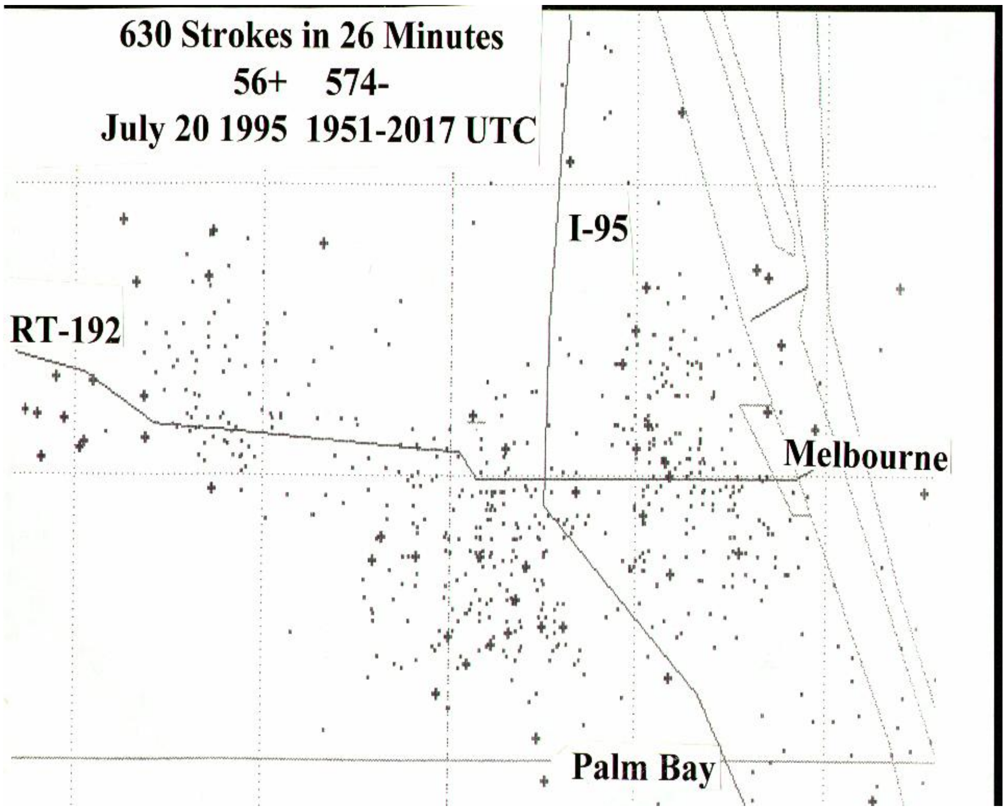

Fig. 3. NLDN display of intense cloud to ground lightning activity. Six hundred and thirty strokes occurred in only 26 minutes. CAPE at this time was approximately 1850 J/KG. Storms initiated when an outflow boundary from the south intercepted the east coast sea breeze.

Preliminary analysis indicate that the cause of the intense lightning activity is twofold. First, the amount of Convective Available Potential Energy (CAPE) over the peninsula needs to be higher than normal. Typically in summer over the Florida peninsula CAPE values range between 1100 to 1300 J/Kg (Hagemeyer et. al, 1991). Higher than normal CAPE is believed to be caused by temperatures aloft being cooler than normal. The second necessary ingredient is boundary interactions. Thunderstorms which form when either the two sea breezes collide (west coast sea breeze collides with east coast sea breeze) or when an outflow boundary collides with one of the sea breezes are very favorable for intense lightning activity, as long as the first condition above is meant.

5. Summary

The LDAR and NLDN systems have shown promise for improving short term forecasting. The LDAR system has also shown evidence for improving aviation forecasting, especially during times when weak convection is embedded stratiform rain events and only in cloud lightning is occurring. In the future, NWS/MLB will continue to analyze LDAR to define unique signatures which could possibly indicate severe storm potential. It has been proposed intense LDAR signatures which form farther aloft are conducive to producing microburst.

In addition to continuing to evaluate the LDAR system, we plan on continuing our overall lightning research. This Includes understanding the social factors regarding lightning casualties, such as time of day, location, tourists vs residents, etc. We also plan to quantify the thermodynamic and mesoscale factors to get a better understanding of intense lightning activity.

6. References

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