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Operational Applications of Lightning Data at WFO Melbourne, FL: A 15-Year Retrospective

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The following is a compilation of excerpts from various articles, pre-prints, technical memoranda, and scientific exchanges involving the operational meteorologists at the National Weather Service Office in Melbourne, FL, with several collaborating scientists from the National Aeronautics and Space Administration (NASA/Kennedy Space Center and NASA/Marshall Space Flight Center), the Massachusetts Institute of Technology/Lincoln Laboratories, and Vaisala Inc. Major interactions involve, but are not limited to, S. Goodman, E. Williams, R. Raghavan, R. Ramachandran, D. Buechler, B. Boldi, A. Matlin, M. Weber, S. Starr, F. Merceret, M. Murphy, N. Demetriades, R. Holle, S. Hodanish, S. Spratt, A. Cristaldi, P. Blottman, M. Volkmer, B. Hagemeyer, and D. Sharp.

1. Introduction

In the fall of 1989, the National Weather Service (NWS) opened their first modernized Weather Forecast Office (WFO) with a commitment to operationally employ state-of-the-science weather observation information. The office was strategically located at Melbourne in central Florida, a region where the occurrence of lightning is greater than anywhere else in the United States. Both climatologically (Hodanish et al., 1997) and statistically (Hagemeyer and Carney, 1996), lightning has been repeatedly proven to be a prime hazard in Florida, often resulting in more casualties and property damage on an average annual basis than other weather-related hazards. From the earliest days, WFO Melbourne engaged in local applied research and scientific community collaborations to find ways to mitigate the effects of lightning and to tend toward the eventual issuance of public watches and warnings. Importantly, the NWS is now acquiring the necessary momentum to realistically consider this critical milestone operationally. As we prepare for this exciting phase, it is appropriate to review at least one of the avenues which brought us to this point. This paper endeavors to provide a retrospective of experiences with respect to the operational applications of lightning data at WFO Melbourne. Initial experiences using real-time cloud-to-ground (CG) data were established through automated dial-up connections and WFO-modified display software. Courtesy access to the Lightning Position and Tracking System (LPATS) was acquired, which utilized the time of arrival technique for locating strikes. Eventually, LPATS would be combined with the Lightning Location and Protection (LLP) system to create an impressive national network. Hence, lightning information was experimentally introduced into WFO Melbourne products and services. Early applications were modest, helping forecasters to simply distinguish showers from thunderstorms, while augmenting radar data prior to the WSR-88D era.

Next, with landmark achievement, total lightning information was introduced into the WFO environment. By 1993, WFO Melbourne had access to the Lightning Detection and Ranging (LDAR) system via the National Aeronautic and Space Administration (NASA) at the Kennedy Space Center (KSC). Developed throughout the 1980s, the system was delivered for operational use in the early 1990s to support the nation's space program for launch, landing, and ground operations. Here, three-dimensional total lightning signals are identified through the depiction of individual point-sources and graphically displayed (Lennon and Maier, 1991). This represented a considerable advancement given that the balance of character of an electrified storm was revealed. In the spirit of collaboration, WFO Melbourne began exploring the potential benefits with regards to serving the general public relative to the protection of life, property, and economic interests (i.e. the agency's mission). Learning from lightning safety experts at KSC and from the United States Air Force's 45th Weather Squadron (45 WS), WFO Melbourne became more proficient in using total lightning information, especially for aviation purposes. Lightning alert areas were configured for the Terminal Aerodrome Forecast (TAF) airports located at Orlando, Daytona Beach, Vero Beach, and Melbourne. The intent was to optimize the use of "TS" (thunder) and "VCTS" (vicinity thunder), and to expedite Local Airport Advisories (LAA). More so, since LDAR was used to issue lightning watches and warnings at KSC, strategies for experimental public watches and warnings were outlined. In fact, WFO Melbourne used LDAR to support the 1996 Summer Olympic soccer venue in Orlando as well as other outdoor festivities. With LDAR, the potential for CG discharge is often evident during those critical periods of first and last strikes or when lightning might travel greater distances from the parent storm channeled through charged cloud or cloud debris.

Together with teams from Marshall Space Flight Center (MSFC) and Lincoln Laboratories at the Massachusetts Institute of Technology (MIT/LL), innovative research was performed to process point-source information into flashes which were associated with specific convective cells and trended. Parallel concepts for trending total lightning flashes obtained from satellite-based sensors were also pursued. A primary thrust was a search for potential severe thunderstorm and tornado indicators to improve lead-time and verification scores. This effort culminated during the 22-23 February 1998 killer tornado outbreak across East Central Florida (ECFL). Integrated with

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radar trend information, total lightning trend information was operationally used during the warning-decision process with promising results. Rapid increases in flash activity were correlated with accelerations within updrafts, while dramatic decreases were followed by collapsing weak echo regions and tornado onset. When properly harnessed, LDAR data can aid the forecaster in discerning severe local storms; this is a powerful declaration.

In 1997, the NWS Southern Region endorsed a project which enabled WFO Melbourne to explore the issuance of lightning outlooks and pseudo-warnings through the Enhanced Lightning Information and Services Experiment (ELISE). Consistent terminology was established by which lightning storms may be described within public products. “Excessive Lightning Alerts” (ELA) are now issued for the public whenever a storm’s primary hazard is considered to be lightning and when its CG rate is twelve flashes per minute averaged over several minutes. Descriptions of onset and cessation may also be included in short-term forecasts. Since that time, procedures and techniques have improved with easy-to-use templates on AWIPS/WarnGen, with CG data delivered directly to forecaster workstations. Uniquely, results of important research in climatology through Florida State University (Lericos et al, 2002) and Texas A&M University (Hodanish et al, 1997) are now used to produce Lightning Threat products in both graphical and gridded form for east central Florida on the Graphical Forecast Editor (GFE). This is done within the Hazardous Weather Outlook (HWO) product, issued officially in textual form and experimentally in graphical/gridded form. The advent of the experimental Lightning Threat product, along with the ELA product, has helped bring the agency to the threshold of a 15-year vision.

2. Discerning Severe Local Storms

Together with teams from Marshall Space Flight Center (MSFC) and Lincoln Laboratories at the Massachusetts Institute of Technology (MIT/LL), innovative research was accomplished by processing LDAR point-source information into flashes which were then associated with specific convective cells and trended. This information was combined with radar parameter information from the local WSR-88D and displayed on the Lightning Imaging Sensor Data Application Demonstration (LISDAD) workstation intently developed for this project (Boldi et al., 1998).

At WFO Melbourne, the research was categorized according to three primary storm types. First, use of total lightning flash information was explored in an attempt to improve warning lead-times for pulse severe storms during central Florida’s warm/wet season (May through September). In these instances, severe weather is often manifested through damaging wet microbursts and marginally large hail. Lead-times are inherently shorter when using traditional data assessment schemes. Second, the mere presence of total lightning was deemed significant for improving the detection of tornadoes associated with the outer rainbands of tropical cyclones. Such tornadoes are spawned within rainband mesocyclones having compact physical dimensions, making them more difficult to discern with radar. Within a favorable thermodynamic environment, the apparent cyclic response of the total lightning signal can be used to trace updraft acceleration pulses which might lead to tornado (re)occurrence through vortex stretching arguments. Third, the 1998 tornado outbreak brought the rare opportunity to evaluate total lightning data within a strongly sheared baroclinic environment. Dramatic increases in flash rates for several of the tornado-producing severe thunderstorms (supercells) were observed. In certain instances, equally dramatic decreases in flash rates were roughly correlated to times of tornado occurrence and the collapse of the bounded weak echo region.

Traditionally, NWS MLB warning meteorologists rely on two sources of information to issue timely and accurate severe thunderstorm/tornado warnings. One source of information is received through detailed reports from storm spotters. This type of information leads to the highest confidence when issuing tornado warnings for ECFL. Unfortunately, storm spotters cannot be deployed in all places (especially in the more rural areas) and at all times (especially at night). As a result, the current primary source of information for the warning meteorologist is the Doppler radar (WSR-88D). Although reflectivity and velocity information has greatly improved the detection of severe storms, limitations still remain such as radar horizon, aspect ratio, and data refresh rates.

Therefore, with respect to lightning information, the question arises whether this data can provide pertinent and timely information to the real-time decision process for the issuance of severe weather warnings. The intent would be to either improve the probability of detection, minimize false alarms, or lengthen legitimate warning lead times. In other words, can lightning data serve as a complement to radar data in order to discern severe storms from non-severe storms and, more directly, to identify those storms which have the potential to become tornadic? This might include the manual integration of lightning data, or perhaps through data integration algorithms in a decision-support system. Past studies have suggested the use of CG information associated to specific violent tornado-producing storms may have some merit. For example, a peak in CG frequency has often been found 15-20 minutes prior to tornado realization with a relative decrease during the time of tornado. However, the total number of CG flashes prior to tornado, or the achievement of a pre-determined peak rate threshold, generally offers little value for prediction (Perez et al., 1997). This indeed appears to be valid for ECFL storms during the cool season (October through May). On occasion, storms have been observed to reverse predominate polarity and lower positive charge to ground signaling the advent of tornado. Unfortunately, this polarity reversal does not always happen and storms can produce a significant tornado without this polarity reversal. Yet, with suspect storms when this does occur, confidence is added to the warning decision process. It has been surmised that the use of CG lightning data, along with radar data, can be useful in determining changes in a storm's intensity and thus its ability to become tornadic. If this is true, then a greater case can be made for the use of total lightning information.

Use of total lightning information for severe storm determination has been experimentally employed during multiple severe episodes at WFO Melbourne (Williams et al., 1998). The scope of preliminary results has been wide within the associated research community, but within the operational arena the scope is much more narrow and tempered with subjective evaluation. The most realistic approach has been to use the data to assess the character of a storm's updraft intensity as an additional proxy-quantity amongst traditional parameters. This becomes more important for storms ill-sampled by radar, either spatially or temporally, or storms that are marginally severe or tornadic. This is true for flash existence, rate, trend, and density with each proving to be more valuable than the corresponding CG signal in most cases. Importantly, application is made according to the appropriate peninsular Florida severe weather regime and different signals become more significant (of more weight) for assessing updraft character and subsequent severe weather potential. Therefore, when blending data from a variety of sensors according to a given environment, total lightning data is uniquely applied. Realistically, total lightning signals are additions to a series of "weighting factors" that can tip the scales of confidence for the warning meteorologist.

2.1. Storms with Strong/Violent Tornado Potential

The potential for strong/violent tornadoes exists mainly during the ECFL cool season which also includes both late season spring (high shear) events and early season fall events. This regime is complicated by the nature in variation of both buoyancy and shear within the environment and the mode of convection that ensues. Simplifying the discussion to the point where a favorable environment for tornadic supercells is known to exist, the following observations can be made. Again, the sample set of known strong to violent tornado-producing supercells in which total lightning information is available is relatively small and thus confined to observational experiences of WFO Melbourne warning meteorologists for this discussion. Yet, three separate signals were tentatively identified for further consideration and study: a minimum threshold flash rate, a lightning "jump" up in flash rate, and a distinct decrease in flash rate. Ironically, these are comparable to the early suppositions of CG data researchers and thus it is not surprising that our research took us in this initial direction. Radar inspections of suspect storms concentrate on the rotational character of the parent mesocyclone (rotational velocity of the mid-level mesocyclone and the increase of rotational velocity and shear into the low levels) and should therefore be matched with their corresponding electrical character. Of the observed tornadic storms (during events which produced at least one known F2+ tornado to include the 1998 outbreak), most were noted to achieve a minimum flash rate (of at least 120 fpm for our study) prior to tornado. ***Note: As a significant caveat for the remainder of this section,*** *flash rate values used are dependent upon "flash definitions and associations" as configured during the time of the study when taking point source information to define a flash and then associating that flash with a storm centroid. Since the study, configurations now have proportionally lower values due to improved flash definition and association schemes. Importantly,* ***there is not a search for "magic numbers," but instead importance is placed upon the relative values and trends***. These storms tended to be the most electrically active storms in the area during their intense mesocyclone phase. Many, in fact, exceeded this low-end threshold with some attaining excessive flash rates (in excess of 500 fpm) and were in stark contrast to other surrounding non-tornadic storms. It could be argued that with the dominance of intracloud lightning activity, the ratio of intracloud to CG lightning could be higher for these tornadic storms. In general, the higher the total flash rate (especially of the core), the more vigorous the updraft and greater the potential for tornado. Storms with high and sustainable flash rates of note (at least 120 fpm) would automatically be placed in the suspect category and would be further examined for radar clues and changes in flash rate trends which may reveal a vigorous and sustained updraft that is actively generating mixed phase precipitation. Nonetheless, of more operational importance is the occurrence of a so called lightning "jump" (see Figure 1).

During previous pulse-severe storm studies, a jump was defined as "an increase in total lightning over a time period of at least 2 minutes, in which the total flash rate increases dramatically (at least 50 flashes) during the entire lightning jump period". Flash rate information, although noisy at times, is one-minute continual and subsequently can be a very useful complement to radar. This is especially true for fast moving developing storms which have tornadic potential which are moving through small counties. During the study period, the rate of radar data refresh was no better than 5-minutes (now 3.5 minutes) and trends in the lightning flash rate can help fill the anxious void. With further marked increases in flash rate, the warning meteorologist could reach a decision before waiting for the next "deciding scan" and thus add several minutes to lead time. This is considered to be a weighty factor when seconds can save lives. Several observations have been made of tornadic storms with more dramatic ramp-ups in lightning activity. Storms in our study which experienced rate increases of more than 100 fpm over a 10 minute period or those which continually trended upward to 120-150 fpm prior to tornado stand out as significant. Although more is to be learned about the relative values, general conclusions regarding the observance of a significant jump-up in flash rate points to a greater likelihood of tornadic development through the deepening and strengthening of the parent mesocyclone circulation. The larger the increase, the greater the chances. Interestingly, in the plan view display, a rather distinct "lightning hole" may present itself coincident in location of the bounded weak echo region as seen within the radar reflectivity depiction. This curious signature can also add confidence to the warning decision process, and add precious minutes to lead times. More so, it is interesting that during the outbreak, some storms continued to experience a flash rate increase even during tornado. It is surmised that perhaps this was associated with cyclic mesocyclones. That is, the current tornado-producing mesocyclone suffers from the occlusion process while a new updraft forms south of the original. The lightning associated with the updraft vigor of the developing mesocyclone is "added" with the lightning with the original storm until such time that they can be separately distinguished. This is one theory.

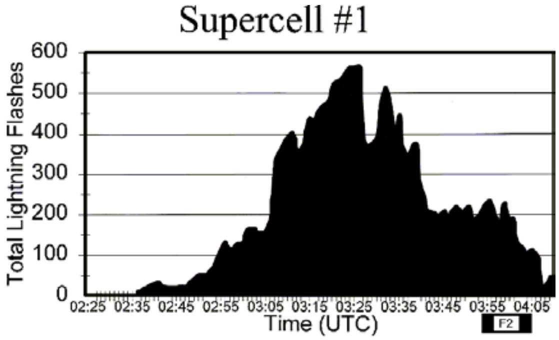

Figure 1. *Trend of total lightning flashes associated with the first tornadic supercell during the East Central Florida Tornado Outbreak (22-23 February, 1998). Note the dramatic increase in flashes as the storm intensified and then the rapid decrease just prior to the onset of an F2 tornado.*

The last signal relates to a noteworthy decrease in flash rate just prior to or during tornado. In some cases, this may be related to the collapse of the bounded weak echo region which already has a correlation to tornado occurrence. For storms associated with moderate to strong mesocyclones which have already realized a minimum flash rate threshold and also experienced a discernible lightning jump, if a distinct decrease becomes evident (during the study period, especially if in vicinity of 100 fpm or more), then the confidence of the warning meteorologist would improve as angular momentum aloft is conceptualized to be lowering toward the surface. This was noted with several of the tornadic storms, but not all of them. Some storms produced a tornado without experiencing this decrease or perhaps the signal was masked by other contributing factors. However, these storms were still marked by the relative high flash rates and lightning jump. In fact, there may be some merit in realizing the length of time a storm is able to maintain an excessive flash rate and its tornadic potential.

2.2. Tornadoes with Tropical Cyclones

Previous tropical cyclone (TC) CG lightning studies have shown that the amount of discharges to the surface vary considerably from TC to TC, but contain very little CG lightning overall relative to mid latitude mesoscale convective systems (Samsury and Orville, 1994). The literature also agrees that most observed CG lightning occurred within outer convective bands, rather than within inner bands and stratiform precipitation regions. This is not surprising since a greater coverage of deep convective cells typically occurs within the outer TC bands where updrafts penetrate far enough aloft to generate mixed phase precipitation (supercooled water and wet graupel) to initiate electrification. The threshold for the production of enough mixed phase particles is generally denoted when a 30 dBZ reflectivity echo reaches or exceeds a height of 8 km AGL or the level of the -15 to -20 deg C isotherms (Forbes et al., 1996).

Issuing tornado warnings during TC situations is an arduous task in which the addition of total lightning information can have a bearing (Spratt et al., 1998). If present, the total signal, of course, dominates over the CG signal. In fact, situations can occur when individual convective cells may possess an electrical character but never produce a CG discharge. In an environment where electrical signals are at many times devoid, the mere presence of a total lightning signal can be a weighty parameter. The majority of TC-associated tornadoes occur within the outer rainbands, usually in a preferred dominant rainband. They often occur in families and are associated with mesocyclones of smaller vertical and horizontal dimension on average. This can make it very difficult to capture a consistent radar signature for warning purposes. In this situation, warning meteorologists are looking for contracting core mesocyclones and increased low-level shear across the cyclonic couplet. These contracting cores often correlate to brief but multiple F0 and F1 occurrences. At times, however small, the existence of total lightning "bursts" can help distinguish these potential tornado-producing storms from other less-threatening cells (Figure 2). It should be noted that in these situations some tornadoes have occurred without any electrical signal at all. Therefore, the use of lightning data cannot be used for warning decisions by itself. Yet, as a radar complement, the character of a given cell can be better inferred, especially in between volume scans and at greater ranges from the radar. For TC tornadoes which acquire F2+ intensity, the electrical character is more difficult to classify. The data set of storms is still somewhat small. Of the two F2+ tornadoes that have occurred in ECFL (with Gordon, 1994; with Josephine, 1996) and also have available total lightning information, both produced lightning bursts at least 10 to 15 minutes prior to (that is, well before) tornado descent and were devoid of activity leading up to tornado and during tornado. Each F2 tornado event possessed a persistent parent mesocyclone with shears in excess of 0.015 s-1 (low-level) and their respective bursts serving to further characterize them as suspect cells.

Interestingly, the use of total lightning information can be used to improve tornado warning statistics for TC-hybrid situations. For hybrid cases, tornadoes may, in fact, be the main TC hazard threat. Outbreaks of short-lived tornadoes are usually the bi-product of mini-supercells which, as previously stated, have inherent radar sampling problems. However, the potential for some sort of lightning signal becomes greater due to baroclinic modifications of the tornado environment (i.e. lower melting level and more shallow mixed phase layer). The weight of importance of the presence of lightning, along with flash rate and flash rate trends, varies according to the situation and the efficiency of lightning production. These signals are mutual with those of the cool season regime situations but are not as pronounced. Nonetheless, a generalized statement can be made that the more intense storms capable of producing significant tornado often have the most associated lightning (relative), and therefore such data can be used to help distinguish those storms. Again, this has worked best in hybrid situations over the Florida peninsula later in the TC season. Oddly, it may offer an additional means for identifying the development of a dominate band or perhaps serve as an actual measure of "hybridness." However, more study is needed.

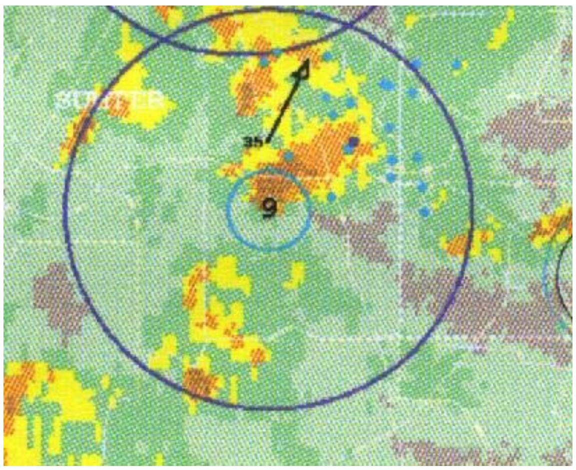

Figure 2. *Example of a subtle but important intracloud lightning "burst" associated with a tornadic storm during Tropical Storm Josephine (over central Florida, 1996). LDAR flashes depicted in light blue.*

2.3. Pulse Severe Storms

Severe storms during the ECFL warm/wet season are usually of the pulse-type variety. The occurrence of tornado is not as threatening since most are weak, localized, and short-lived in the presence of a weakly sheared environment (often of the non-descending variety). In fact, there have been very few cases with tornado casualties within this environment. In all actuality, damaging wet microbursts (and the occasional occurrence of large hail) pose the greater threat. Difficulty arises with the inherent short lead time for warnings. Statistically, the false alarm rate also suffers in such circumstances. To improve on this matter was, in fact, the original incentive for WFO Melbourne to engage in the TLI/LISDAD project. Fortunately, there are many more sample cases related to this type of severe storm discernment (Hodanish et al., 1998).

Similar to the strong/violent tornado cases, when attempting to identify pulse severe storms, the dramatic rate increase ("jump") of total lightning and subsequent rapid decrease were highly correlated signals. In particular, a rapid increase in intracloud flash rates usually preceded severe weather manifestation at the ground by 1-15 minutes. These "jumps" tended to be about 20 to 100 fpm/min (Figure 3). The higher the jump, the greater the likelihood of severe weather since such relationships result from the development of mixed phase precipitation and increased hydrometeor collisions that lead to greater efficiency in charge separation (Goodman et al., 1998). Increased confidence in severe weather occurrence was attained when this "jump" occurred once a storm had already achieved a notable level of intracloud activity (60-120 fpm) that would mark an upward acceleration of the updraft. Importantly, however, severe weather generally occurs during the collapse phase (downdraft dominated phase) of the pulse storm. During this phase, intracloud activity tends to sharply decrease. Generally, warning lead times were lengthened by several minutes, especially when teamed with radar parameters. As additional experience and trust is gained, it is believed that a greater increase in lead time will be realized along with a gradual reduction in false alarms.

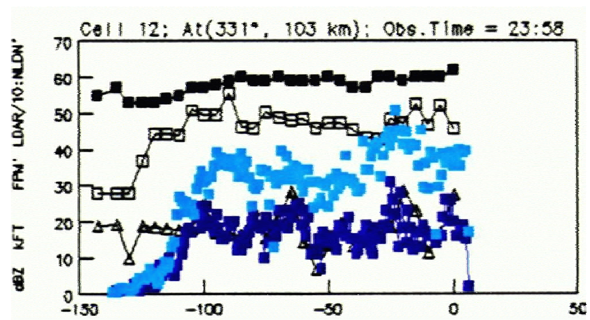

Figure 3. *Pulse severe storm over central Florida showing a rapid increase in flash rate (factor 10) with time well before severe weather manifestation (at -65 minutes). Intracloud activity in light blue, cloud to ground in dark blue. Traditional radar parameters of maximum dBZ, height of maximum dBZ, and echo tops are also shown.*

3. Improving Aviation Forecasts

Another area of application of total lightning information deals with improving aviation forecasts at four ECFL airports. This includes the timely inclusion, removal, and use of "thunder" and "vicinity thunder" (TS/CB and VCTS) in the Terminal Aeordrome Forecasts (TAFs). Intentions have been to optimize the use of total lightning information for the issuance/amendment of these TAFs to more accurately reflect the 0 to 2-hour time frame during convective situations. Positive results have been yielded to help fulfill the demanding need for accurate and precise flight planning and routing information. A parallel function has been to support several local airports with lightning information for ground operations in the form of Local Airport Advisories (LAA). In all, the early detection of electrical discharge within both the 5 nmi and 10 nmi cylinders of space over each runway complex has been deemed beneficial in this regard. Since April of 1996, WFO Melbourne has routinely issued Terminal Aerodrome Forecasts (TAFs) four times daily for the following four sites: Daytona Beach International Airport (DAB), Orlando International Airport (MCO), Melbourne International Airport (MLB), and Vero Beach Municipal Airport (VRB). During the warm/wet season, the aviation forecaster routinely issues TAFs which include forecasts of afternoon thunderstorms (TS) for a period of between three and six hours, with four hours being the most common forecast time span. WFO Melbourne is well aware of the importance of balancing airlines' needs for both cost-effectiveness and safety when it comes to composing TAFs. The inclusion of TS and accompanying IFR (instrument flight rules) ceilings/visibilities in either the prevailing or TEMPO group of a TAF has significant consequences with respect to airport operations, particularly if it is a major hub (Ott and Ladd, 1994). For instance, not only are the number of arrivals/departures reduced during TS/IFR conditions, but any aircraft whose destination airport contains a forecast of prevailing or TEMPO TS must carry additional fuel so that it may reach a designated alternate destination airport should the weather not permit a landing at the planned destination airport.

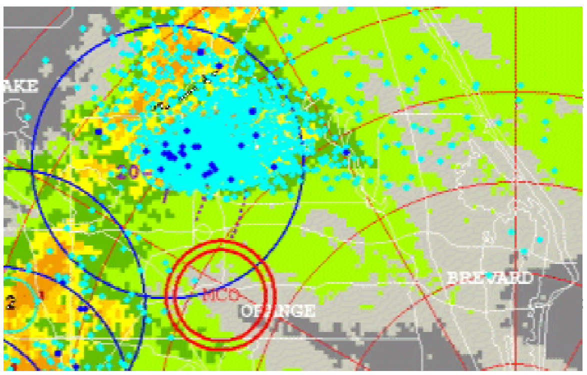

Figure 4. *Example of circle alerting icon centered around the Orlando International Airport (MCO) for intracloud lightning detection. Red denotes that intracloud lightning is occurring (or has occurred within the past 15 minutes) within 5 nmi of the center of the runway complex.*

Carrying this extra fuel costs the commercial carriers more money, and if TS conditions are inaccurately (or excessively) forecast, the cost incurred by a commercial airline can become quite large.

During an evaluation period, forecasters concentrated on the exploitation of available total lightning information (TLI), with emphasis placed on the initial two-hour time period. Software from both the LDAR and LISDAD workstations was configured to incorporate lightning alerts for each of the TAF sites. On LISDAD, these visual alerts display whenever lightning is detected at specified distances. A circle icon is placed around the TAF site (Figure 4) in which its color coding denotes the current level of lightning threat. If the circle icon is black, there is no TLI within 20 nmi; if cyan, there is TLI within 20 nmi but not within 10 nmi; if yellow, there is TLI within 10 but not within 5 nmi; and if red, there is TLI within 5 nmi. A 15-minute safety time lag has been introduced as the threat decreases. One major goal within this 0 to 2-hour time period was to optimize the forecast for thunderstorms (TS), convective wind gusts (GxxKT), and IFR (instrument flight rules) ceilings/visibilities conditions in both the prevailing and TEMPO groups, and to narrow the time frame in which "extreme" thunderstorm-related aviation weather (e.g. low IFR ceilings/visibilities, wind gusts in excess of 30KT) to one hour or less, when warranted. Another intent was to establish whether "TS VCSH" as a prevailing weather group was preferable over the use of "VCTS." In all, the forecasters have found favor with the alerting feature and it is regarded as a very useful feature.

Additionally, in order to determine the need for enhanced aviation service via Local Airport Advisories (LAA), the airports for which LAAs are currently issued (DAB and MCO) were visited. During these visits, it was determined that MCO did not require this level of service, since they had access to NLDN data and already had a system in place for alerting operational personnel to the presence of lightning. However, authorities at DAB were interested. As a result, LAAs are issued for storms that possess (or forecast to possess) excessive amounts of CG lightning in close proximity to DAB (in support of ground operations). Insights from the ongoing effort suggest that placement of an economical automated system (similar to the TAF alerting) would ultimately work best since ground operations can also be negatively impacted by lesser amounts of CG lightning.

4. Lightning as a Direct Hazard to the Public

Finally, yet another total lightning application (perhaps the most challenging) is being examined to consider the direct hazards of lightning to the public. Florida is a leader in both CG strikes (annual flash densities) and lightning casualties. During the summer of 1997, WFO Melbourne began including lightning information into public products. Climatological, statistical, and safety information are now included in the morning edition of the Hazardous Weather Outlook (HWO) product according to the current synoptic and mesoscale weather pattern. The HWO is a product intended for public and interagency planning purposes and was used to describe the geographical distribution and timing of the onset/ending of deadly CG lightning strikes. Particular attention is given to lightning-sensitive situations where larger numbers of people are expected to be outdoors away from ready cover. Then, as each convective event unfolds, lightning information is included in the Short-term Forecast (NOW) product. LDAR information is used to detect early signs of electrical activity aloft over/near generalized areas before actual CG strikes occur or to help determine when the potential for CG discharge has diminished. Situational casualty statistics indicate that the onset and end of CG strike activity are dangerous times. By the end of the 1997 season, a modest but promising success was achieved which has since been built upon.

In a study conducted by Curran et al. (1997) it was found that during the period from 1959 through 1994 Florida experienced more lightning-related casualties (1523 deaths and injuries) than any other state in the country. In fact, Florida experienced over twice the amount of casualties than even the second leading state (Michigan). During this same time period, CG lightning was responsible for 53 percent of the total weather-related (phenomena) deaths in Florida; more than hurricanes, floods, and tornadoes. On average, ten people are killed each year in Florida with an average of thirty four injuries (Paxton and Morales, 1997). Climatologically, central and south Florida experience the most CG lightning in the state (Hodanish et al., 1997) with flash densities maximizing in the summer months and during the afternoon. This corresponds well with the location, season, and approximate time of day of most lightning-related casualties. Yet, despite the overwhelming statistics, the NWS does not formally address lightning as a direct and advisable threat in their forecast and warning product suite. Since lightning strikes the ground in such large numbers and is so widespread, it is not possible to warn for every lightning flash for each person (Holle and Lopez, 1998). Nonetheless, with recent advancements in lightning sensor technology and data availability, the desire to satisfy the agency mission must be sought after in this regard. Few places actually issue routine lightning-specific advisories as those intently issued at KSC, although the feasibility is being investigated. At times, other non-routine advisories have been issued to support certain special events such as major golf tournaments and the outdoor venues during the 1996 Summer Olympic Games (Rothfusz et al., 1998; Powell and Rinard, 1998; Watson and Holle, 1996).

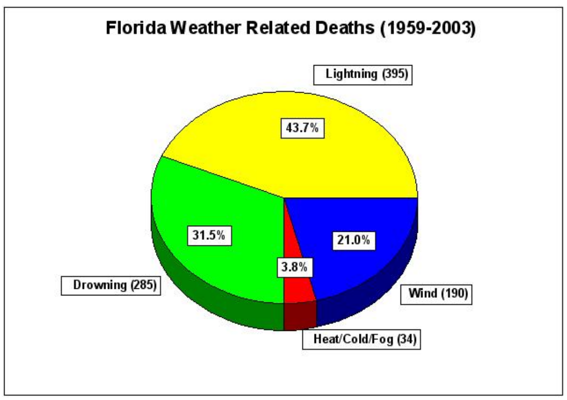

Figure 5. *Pie chart denoting Florida weather-related deaths by hazard from 1959 through 2003. Lightning is the leading cause of casualties. From Hagemeyer.*

4.1. The Hazardous Weather Outlook

The HWO is a specialized product created by the NWS for the purpose of describing the near-term threat of anticipated weather hazards. In Florida, it is usually issued between 6-7 AM so that the potential threat for all forms of hazardous weather can be factored into day-to-day planning by its users. Among groups with the greatest lightning risk are those assigned to outdoor work details or those planning outdoor recreational activities. Specifically, the HWO can be used to describe the anticipated electrical character and distribution of forecast thunderstorms (Sharp, 1998). For example, it is used to delineate minimal threat situations when non-electrical showers are expected rather than thunderstorms. The HWO is also used to take advantage of recent flash density climatologies, as well as statistical study results highlighting geographic areas and socio-circumstances which are at greater risk according to the particular meteorological regime. Another beneficial use of the HWO is to offer a generalized description of the expected "onset" and "ending" of CG lightning over such locations as the central Florida attractions area and the more popular beaches. It provides the NWS with the opportunity to express whether lightning will perhaps begin during the early or late afternoon and from which direction it will likely approach. Educational facts and situational "calls-to-action" are also incorporated to emphasize safety. It is deemed essential to inform people before they start their day. An informative HWO (Figure 6) can satisfy this need.

...EXCESSIVE LIGHTNING EXPECTED OVER THE COASTAL COUNTIES OF EAST CENTRAL FLORIDA...

WITH THE ATMOSPHERE OVER CENTRAL FLORIDA REMAINING MOIST AND UNSTABLE...DEADLY LIGHTNING STORMS WILL DEVELOP OVER THE AREA AGAIN THIS AFTERNOON. SINCE THE HIGH PRESSURE RIDGE AXIS WAS LOCATED SOUTH OF CENTRAL FLORIDA...THE SURFACE WINDS WILL BE FROM WEST. THEREFORE...THE EARLIEST OCCURRENCES OF CLOUD-TO-GROUND LIGHTNING WILL BE OVER INTERIOR SECTIONS IN VICINITY OF LEESBURG... SANFORD...ORLANDO...AND KISSIMMEE DURING THE EARLY AFTERNOON. AS THE AFTERNOON PROGRESSES...LIGHTNING STORMS WILL INCREASE IN NUMBER AND CLUSTER TOWARDS THE EAST COAST WHERE THE EAST AND WEST COAST SEA BREEZES ARE EXPECTED TO COLLIDE LATE IN THE AFTERNOON. EXCESSIVE LIGHTNING AT A RATE EXCEEDING 12 STRIKES PER MINUTE WILL LIKELY OCCUR WITH SEVERAL STORMS FROM DAYTONA BEACH...TO COCOA BEACH...TO VERO BEACH...TO FT PIERCE. LIGHTNING WILL APPROACH THESE LOCATIONS FROM THE WEST.

WITH THE WARM WEEKEND WEATHER...MANY CENTRAL FLORIDIANS WILL BE TEMPTED TO ENGAGE IN OUTDOOR ACTIVITIES TODAY. REMEMBER...THE THREAT OF LIGHTNING USUALLY ARRIVES BEFORE THE RAIN. AT THE FIRST SIGN OF AN APPROACHING OR DEVELOPING STORM...MOVE QUICKLY INDOORS. AFTER THE STORM HAS PASSED...BE CAUTIOUS WHEN RETURNING OUTDOORS. MANY LIGHTNING-RELATED DEATHS OCCUR WHEN PEOPLE VENTURE OUT TOO SOON.

Figure 6. *Hazardous Weather Outlook Product*

Experimentally, WFO Melbourne is also issuing a suite of graphical products to support the textual HWO. Here, a variety of individual hazards are depicted through a series of threat graphics, to include the lightning threat. Information is conveyed in index form on a color-coded scale from 0 (no threat) to 5 (extreme threat) for the Day-1 period (Figure 7). Here, probabilistic information (through traditional guidance and histories of CG frequency are teamed with expectations of electrical character of anticipated storms. During the warm season, forecasters make significant use of climatologies of CG flash density according to the wind flow regime (Lericos et al., 2002). The target audience is unsophisticated users through the use of the world wide web.

4.2. The Short-term Forecast (NOW)

The NOW is a short-term forecast product (usually 0-2 hrs) used to depict significant weather which will affect an area. The NOW is flexible in that it can be issued for individual counties or for an entire

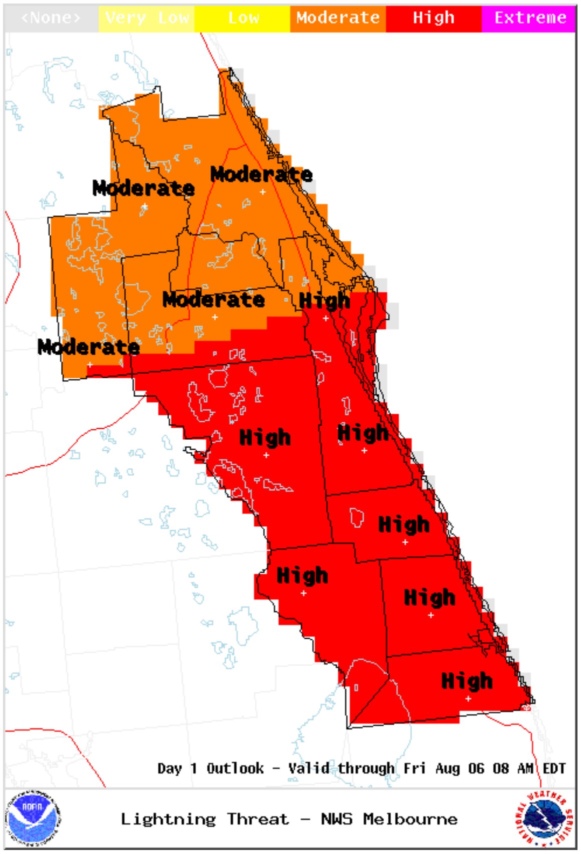

Figure 7. *Example of the experimental Lightning Threat graphic issued daily at WFO Melbourne. It is largely based on the likelihood that CG lightning will occur combined with anticipated flash rate.*

county warning area. During the summer of 1997, it was found that relevant lightning information could indeed be included within the NOW (Figure 8). Initial efforts were meager, focusing on the onset period over generalized areas. In tandem with radar, LDAR was used for the early detection of developing electrical convection before imminent ground strikes while CG data was used when handling the movement of mature thunderstorms from location to location. In order to heighten awareness, the term "lightning storm" is employed whenever CG lightning is considered to be the primary hazard. This has been well received and accepted by the media and adopted into their nomenclature. Operationally, the handling of the onset of lightning was found to be plausible for the first strikes of the day over a given area, but quickly becomes unmanageable when attempting to accommodate the reoccurrence of lightning.

THROUGH 1 PM...THE FIRST LIGHTNING STORMS OF THE DAY WILL FORM OVER INLAND SECTIONS FROM OCALA TO LEESBURG...AND NEAR THE ORLANDO / KISSIMMEE ATTRACTIONS AREA. FREQUENT LIGHTNING AND LOCALLY HEAVY RAIN WILL BE ASSOCIATED WITH INCREASING STORMS INTO THE MID-AFTERNOON. AT THE FIRST AUDIBLE OCCURRENCE OF THUNDER...MOVE QUICKLY TO SHELTER AWAY FROM WATER. DO NOT SEEK SHELTER UNDER TALL TREES. IF YOU ARE IN A SITUATION WHERE YOU CAN NOT HEAR THE APPROACH OF A LIGHTNING STORM...WATCH FOR DARK THICKENING STORM CLOUDS. REMEMBER...MORE PEOPLE ARE KILLED IN FLORIDA BY LIGHTNING THAN BY ANY OTHER WEATHER HAZARD.

Figure 8. *Short-term Forecast Product*

Similar to the onset, the (absolute) ending of CG activity over a generalized area was found to be practical information to include in the NOWs. This loosely mimics the "all clear" concept. Both LDAR and CG data were used with a temporal safety margin added. According to Holle et al. (1992), most central Florida lightning casualties occur late in the storm. This suggests that a more definitive effort should be made in this area. Collectively, WFO Melbourne has been unable to handle both the onset and ending of CG lightning during all times and in all locations. Manually, this task is too daunting and requires unreasonable human resources.

During periods when lightning is already in progress, forecasters also attempt to describe the frequency of CG discharge in the NOWs. In the past, the need for this type of information always seemed necessary but the actual usefulness was unknown. Although somewhat arbitrary, seemingly reasonable quantitative values have been attached to descriptive terms. The term "occasional" is defined as lightning associated with a storm with an average rate of 2 CG strikes per minute. It is important to note that this term is rarely used in products since it is felt that it tends to minimize the actual threat and could inadvertently lure people outdoors into harms way. The term "frequent" is defined for lightning storms possessing an average rate of 3 - 11 CG strikes per minute, while "excessive" referred to lightning storms with average rates greater than 11 strikes per minute (more than 1 CG strike every 5 seconds). Both terms are used within NOW products with the term "frequent" used most often. These descriptive terms tend to have greater impact when actual numerical rates are also included in the product.

4.3. The Excessive Lightning Alert

As a current practice, once a storm reaches the "excessive" category, a Special Weather Statement (SPS - Figures 9 and 10) is issued for the impacted county or counties. This pseudo-advisory is called an Excessive Lightning Alert (ELA) and has evidence of value both in the protection of life and in the protection of property. The scenario which most often prompts the issuance of an ELA is the collision of the east and west coast sea breezes during the summer peak season, or with certain storms which exploit the sea breeze. The parallel collision and merger of sea breezes often accentuates thunderstorm production which results in "excessive" lightning. At times, isolated storms also reach and maintain excessive rates on their own and ELAs are issued as they move from one county to the next. Many times, excessive rates are associated with damaging thunderstorms. In these cases, the storm is no longer referenced as a "lightning storm", but rather as a "severe thunderstorm" capable of producing the traditional damaging wind/hail hazards and thus prompted the usual appropriate weather warning. Even so, it was considered valuable to describe the frequency

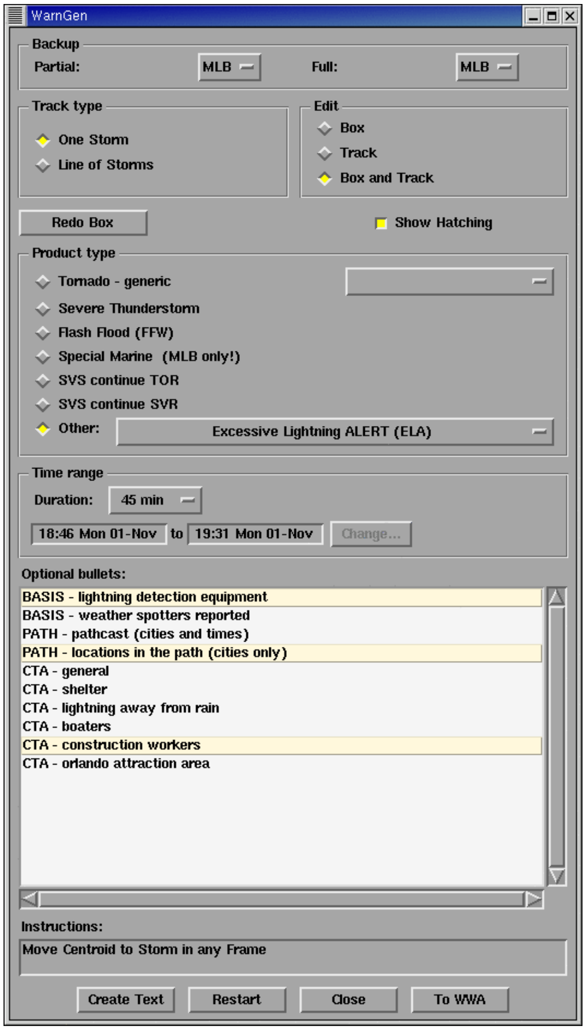

Figure 9. *The Excessive Lightning Alert product can be easily generated by forecasters on AWIPS/Warnen.*

of the CG lightning, referring to it as the first storm hazard to arrive in a given area and the last hazard to depart. It was surmised that this could actually result in quicker public reaction to move indoors to safety (regardless of the thunderstorm hazard).

The ELA represents a storm-relative approach to lightning advisories. In order to accomplish this, it was necessary to associate individual CG strikes with respective storms. This was not always easy and certainly lends itself for automation (i.e. AWIPS/SCAN). Other approaches yet to be explored might entail a geo-relative approach or a person-relative approach. In a geo-relative situation, advisories would be issued for specific locations (similar to KSC advisories) and could include "onset" and "ending" criteria, providing the location was not overwhelmingly large. The person-relative approach is too specialized and intensive for the NWS to pursue.

...EXCESSIVE LIGHTNING STORM OVER BREVARD COUNTY...

THROUGH 6 PM EDT...A STORM PRODUCING EXCESSIVE LIGHTNING WILL AFFECT PARTS OF BREVARD COUNTY FROM NEAR TITUSVILLE...TO THE KENNEDY SPACE CENTER...TO PORT CANAVERAL AND COCOA BEACH. THIS STORM WAS PRODUCING GROUND STRIKES AT THE RATE OF 12 TO 15 PER MINUTE AND IS ESPECIALLY DANGEROUS. THOSE WITH THE GREATEST DANGER ARE PEOPLE IN NORTH BREVARD COUNTY ENGAGED IN OUTDOOR ACTIVITIES SUCH AS BOATING, SWIMMING, OR PLAYING GOLF. DUE TO THE GREATER NUMBER OF STRIKES...THERE IS AN INCREASED THREAT TO LIFE IF LIGHTNING SAFETY RULES ARE NOT FOLLOWED. THE EXCESSIVE FREQUENCY OF STRIKES WILL ALSO BRING A GREATER CHANCE FOR DISRUPTION IN ELECTRICAL POWER SERVICE AND RELATED PROPERTY DAMAGE.

Figure 10. *The Excessive Lightning Alert Product*

4.4. Implications

So far, a greater emphasis has been placed on the protection of life rather than property. Both the "onset" and "ending" of CG lightning are accommodated through routine short-term forecasts. Pseudo-advisories (ELAs) focus on excessive strike rates which address both life and property. Adaptive automation schemes for prescribed alert thresholds for the presence of LDAR activity aloft over defined areas, as well as CG rate activity associated with individual storms should be pursued. A true test of the value-added aspect of real-time lightning data will be whether meaningful information can be extracted from the data stream which can be used to protect the public from deadly CG lightning strikes.

a. Peak Season Experiences - Accommodating lightning as a direct and advisable weather hazard is most effective during the peak season. During the summer, casualty statistics are more readily used as a motivating force for the protection of life. Also, lightning storm occurrence is more diurnally-driven and often associated with either the east coast sea breeze or west coast sea breeze. Determining the general time and location of the onset of lightning is normally a function of the low-level wind flow regime or related with the presence of mesoscale boundaries. Electrical convection usually develops in situ over central Florida as opposed to advecting into the area (i.e. with frontal systems). Excessive lightning usually results from storm mergers or from the collision of the east and west coast sea breezes. Lightning ground strikes are maximized during the afternoon when most people are coincidently engaged in outdoor activities. Since a larger percentage of out-of-state tourists is typically present in the summer and may not be fully aware of the Florida lightning threat, product composition should be continually sensitive to "calls-to-action" and safety rules. Lightning information is rarely incorporated into products during the overnight period (after 10 pm).

b. Lull Season Experiences - From October through May, electrical convection is usually associated with larger mid-latitude systems with infrequent day-to-day occurrence. Lightning information is far less likely to be included within public products and more likely to be used to determine thunderstorm severity. When included, it is often used with major calendar events (such as College Spring Break) or weekends in mind. No specific references to life saving actions are made available in public products issued after dark. During the lull season, ELAs are rarely issued. In almost all ELA situations, excessive rates are either associated with severe storms or with storms which occur overnight, but on occasion have been issued in advance of severe thunderstorm warnings and providing heightened awareness.

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