# 8.4 MODERATE AND HIGHER CLOUD TO GROUND LIGHTNING WITHIN TROPICAL CYCLONE FEEDER BANDS ON THE FLORIDA PENINSULA

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## 1. ABSTRACT

An aspect of tropical cyclone activity that has to be accounted for is the lightning strikes they produce within their outer feeder bands and the state of Florida is a leader for both in the United States. Identifying the conditions favorable for moderate and higher cloud to ground lightning strikes can mitigate some of the risk utilities face when dealing with the many hazards tropical cyclones provide. These moderate and higher cloud to ground lightning densities are defined as a minimum of 76 lightning strikes in a 5 X 5 km grid space over 1 hour of time. As an adjunct part of the broader Florida Thunderstorm Index, a meteorological examination of how these impactful lightning storms have occurred is the main subject of this paper. Often these feeder band thunderstorms run counter to the broader averages of moisture and instability based on their steering flows that thunderstorms driven by other micro, meso and synoptic scale patterns bring about (Smith, 2015). Moderate or higher lightning storms in feeder bands can impact areas beyond the bounds of hurricane and tropical storm advisory areas as well as ahead of and after any issuance. While utilities prepare for wind and flooding, lightning strikes can add additional resources straining native and mutual assistant crews. Often these feeder band thunderstorms happen hundreds of miles away from the center of a tropical cyclone circulation and many times in the formative stages of a tropical cyclone. A common thought is that tropical depressions, tropical storms and hurricanes do not produce much lightning and while that may be true compared to sea breeze thunderstorms in Florida, this hazard cannot be discounted and must be part of a utilities assessment plan before an imminent tropical system gets named and also days later during the restoration process. The data analyzed for this paper compiles steering flow, moisture content and instability levels within tropical cyclones that have impacted Schneider Electric's Florida energy clients from 2007-2014. This period was especially noted as one that did not see a single hurricane make landfall in Florida yet from nearly each tropical system that impacted the peninsula, moderate and higher lightning storms from outer bands occurred. The paper also looks into the tracks of these tropical cyclones determining which tracks produced the greater density of lightning relative to location in Florida. Some of these thunderstorms occurred just prior to a system being classified a tropical cyclone and were also analyzed. Disruptions to utilities have occurred with these feeder band thunderstorms though the discrepancy between whether it was lightning and/or other factors such as the winds are difficult to ascertain. Nevertheless, while a “hidden danger” in the public due to tropical cyclones is the flooding, to utilities this may be in the form of higher lightning strikes which like the rise in water can have far reaching impacts.

## 2. BACKGROUND

Yearly the state of Florida has some of the highest lightning densities in the United States with on average over 1.5 million

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lightning flashes (Netquote.com, 2015). Within the utility service territory of one of our Florida electric companies utilized for this paper the estimates are that there are more than 250,000 lightning strikes per year. This number contributes to being among the world leaders annually among lightning strikes (Mn.floridaweekly.com, 2015). When it comes to tropical cyclones, Florida is also a bellwether for activity in the United States. Over 450 tropical storms or hurricanes have struck Florida since before the 1800s (World Digital Library, n.d.). Since 1851, essentially since reliable tropical cyclone records have been kept, about 4 in 10 hurricanes that have made landfall in the United States have crossed into Florida. It has been since 2005 however that Florida has had a hurricane landfall (Blake, Landsea & Gibney, 2011). But the impacts of lightning go beyond just hurricane hits and as one will see in this paper there are issues from lightning in tropical storms and depressions as well. According to Hurricanecity.com, 22 Florida cities are listed in the top 50 tropical storm and hurricane prone cities since 1871 (Hurricanecity.com, 2015).

There is a fascinating intersection of lightning and tropical cyclone activity that has not been documented at great length. But this certainly is not a 1:1 ratio in rank for Florida. On first thought, one would not equate much in the way of lightning associated with tropical cyclones. That is a reasonable assumption since charge separations for lightning formation are not as likely within a moist, tropical regime. Also the updraft speeds within tropical cyclones are not as robust as those thunderstorms with a more baroclinic atmosphere in place where freezing levels are lower (Hargrove, 2012). So despite the fact that lightning and tropical cyclone strikes prevail more in Florida than any other state, it does not mean that there are an abundance of lightning strikes with every tropical system. This was found in the analysis as well for this paper. But with top ranks in both lightning and tropical cyclones it is reasonable to assume that lightning strikes can be more of an issue by the numbers.

This paper dives deep into the meteorology cataloging the lightning storms that occurred which can help in forecasting the different levels of lightning -- Levels 2-6 in which Level 3 and higher is most impactful to energy operations -- within tropical cyclones on the Florida Peninsula. Figure 1 displays the scale used to identify lightning storms created in 2010 with consultation with the Florida energy client analyzed in this paper.

| Lightning Level Scale | Cloud to Ground Lightning Strikes in a 5 x 5 KM Grid Per Hour | Lightning Storm Descriptor |
|---|---|---|
| 2 | 1-75 | Light |
| 3 | 76-150 | Moderate |
| 4 | 151-300 | Strong |
| 5 | 301-450 | Severe |
| 6 | 451+ | Extreme |

**Figure 1:** *Lightning scale broken down into 6 levels. This corresponds to the amount of lightning strikes in a one hour period within a 5 X 5 km grid.*

The Smith Florida Thunderstorm Index was created in 2007 and has been subsequently updated with more lightning data since then and it is a go to for helping to forecast lightning levels within thunderstorms (Smith 2015). The back bone is the 850 hPA steering flow with instability and moisture

levels also used in the form of the lifted index (LI), precipitable water (PW) and K Index values. This index is tailored to the different regions of Florida as the orientation of the steering flow's impact on lightning storms can vary from one end of the Florida Peninsula. Sea breeze and lake breeze boundaries are influenced by the steering flow and their interactions can help determine lightning intensities. Using 850 hPA wind speed and direction as a starting point in the forecasting analysis of these lightning storms as well as archiving such data is important because it lies above the frictional effects of the boundary layer. This can act as a driver of the sea breeze circulation that tops out about 2,000 feet below the typical elevation of the 850 hPA flow (Sea Breezes, Print Version).

There have been quite a few studies explaining methods of forecasting for lightning strikes in Florida. These have differed when it comes to steering flow, a vital part of my thunderstorm index, especially. NASA utilizes the mean 1000-700 hPA layer wind direction as the flow regime in Cape Canaveral and places importance on the placement of the subtropical ridge with respect to wind direction elsewhere in the Florida Peninsula (Bauman III, 2011). Lericos et. al. (2002) from Florida State also chronicled the subtropical ridge for lightning from May to September. A layered approach to the flow regime is a more comprehensive examination of the steering flow than looking at one level though in the final analysis, the direction at 850 hPA matches close to the mean and with its position above the sea breeze circulation on a day to day operational level is satisfactory. With using the mean layer as well, there may be multiple regime flows that fit a lightning event which on a broad scale is very reasonable (Lericos et. al. 2002). For my thunderstorm index, it is site specific on the Level 3 and higher cell or cells at a given location. Also with respect to the subtropical ridge an inference to 850 hPA wind can also be made and on occasion, especially with a tropical cyclone in a weak state or one in transition, more of a trough pattern can take hold eliminating the ridge response when it comes to flow regime. NASA also has used instability and moisture to help in diagnosing lightning storms with an index called the Thompson Index (TI) (Bauman III, 2011). It was found by NASA that the TI is one of the best indices for lightning in the warm season (Bauman III, 2011). While my scale does not combine them explicitly there is good value in doing so especially when there is high instability and high moisture content. However flaws in this are noted when the moisture content is high while the instability is lower. This can cause a false causation driving up the TI but not necessarily equating to more lightning. A scenario like this happens more often in tropical cyclone situations as well as in very moist setups more so than day to day sea breeze thunderstorms. It is important to note that NASA and others are not forecasting lightning intensities on a scale like what my thunderstorm index intends to do and is more focused on the warm season rather than year round like my index.

The analysis for this paper uses Level 3 and higher lightning instances from tropical cyclones that impacted one of Schneider Electric's Florida energy client's territory from 2007-2014. Figure 2 is a display of the territory boundaries.


**Figure 2:** *Our Florida energy client's service territory divided into 4 regions: North, West, East and South.*

There were 46 such instances documented spanning 17 tropical cyclones during the period as noted below in Figure 3.


**Figure 3:** *Tracks of the 17 tropical cyclones that produced Level 3 and higher lightning in the Florida energy client's territory from 2007-2014 (Coast.noaa.gov, 2015).*

## 3. HYPOTHESIS

As an operational meteorologist focused on the energy sector who has forecasted for Florida since 2006, I have theories on what I think may be true when it comes to tropical cyclone related lightning based on observations I have noticed. These will be proven or disproven in the following text of the paper. So I think that:

1. There would be at least one level 3 and higher lightning storm from all tropical cyclones that impacted our Florida energy client.
2. The highest Level 3 and higher lightning instances would occur in tropical cyclones that were over the Gulf of Mexico and in the developing stages.
3. The fewest Level 3 and higher lightning instances would be in tropical cyclones that pass east of the state and within the inner core.
4. Most of the Level 3 lightning instances in tropical cyclones would impact the Florida energy client's territory away from where tropical storm and/or hurricane advisories were in place.
5. 850 hPA speeds would be higher, LI's would be more unstable and PW's and K's would be higher than averages from all Level 3 and higher storms in the Smith Florida Thunderstorm Index for tropical cyclone related lightning.

## 4. DATA ANALYSIS

Regarding Hypothesis 1, the thought was that the impact from tropical cyclones and their feeder bands to the Florida Peninsula would result in at least one instance of Level 3 or higher lightning from 2007-2014. That was not the case. Overall there were 24 tropical cyclones during the period of record and 7 did not have an instance of Level 3 lightning within our Florida energy client's territory. Those 7 (Noel, Cristobal, Gustav, Hanna, Claudette, Ida and Nicole) either tracked far enough away that kept feeder bands with enough lightning to make it into the territory or did produce Level 3 and higher lightning but outside of the territory which was the case in Gustav in 2008 which had Level 3 and 4 lightning between the South and West regions or where tropical systems that were not highly electrified. This is no surprise as studies have shown that lightning distribution can range widely within tropical cyclones (Molinari, Moore and Idone, 1999).

With regard to Hypothesis 2, the common thought would be that the northeastern quadrant of a tropical cyclone would be the “dirty” side, the part of the system where the worst weather would occur such as the heaviest rain, isolated tornadoes, presumably more of the lightning activity and the strongest winds. With respect to the wind, that is not necessarily true as it depends on the actual movement of the tropical cyclone with the forward right quadrant providing the worst conditions (Sealls, 2015). A tropical cyclone tracking over the Gulf of Mexico would ideally put Florida in that forward right quadrant and infer higher lightning instances. Of the 17 tropical cyclones analyzed, 9 of them were in the Gulf or moved inland from the Gulf. These Gulf tropical cyclones accounted to 41% of the Level 3 and higher lightning instances that were recorded. This was not the highest percentage though for tropical systems impacting Florida tracking over or into the Gulf, the Atlantic, to the south of the state or over the state. But more tropical cyclones did impact the service territory while being over or inland from the Gulf. The highest level of lightning from one of these tropical cyclone feeder band thunderstorms was at Level 4. Of the levels of lightning most were either peaked at Level 3 or Level 4 but there was one Level 5 but it was not from a Gulf system. So the correlation between a tropical cyclone in the Gulf leading to higher intensities of lightning did not come to being though more lightning instances did occur. Thinking about the proximity of these Gulf tropical cyclones, one may think that the West region of our Florida energy client’s territory would be most impacted. But it was the North region that took more of these Level 3 and higher lightning storms from tropical cyclones impacting the Gulf, 53% of the instances. The East region which covers less territory than the North had the second most at 26%. West region had 21% of the instances. As can be imagined the dominant 850 hPA wind direction was a southerly component in all but one instance and that featured an easterly 850 hPA wind.

Increased lightning activity may be a tell-tale sign of a developing and intensifying tropical cyclone. This has especially been noted in outer feeder bands where vertical shear is at a maximum with a minimum closer to the inner core (Schumacher and DeMaria, 2015). For developing tropical cyclones where the upper level environment is not usually as pristine as a mature or maturing tropical cyclone the thinking is that there would be more instances of Level 3 and higher lightning storms. Three tropical cyclones were identified in this analysis (Tropical Depression 10, Bret, and Dorian) and there were 5 instances from these developing systems. Of the 5 instances just 1 was not either Level 4 or 5 lightning storms. This developing setup featured the only Level 5 lightning storm observed which occurred in the developing stages of what would become Tropical Storm Bret. Each instance featured lightning storms on the very outer feeder bands which were enhanced by sea breeze boundaries. While the 850 hPA wind directions and speeds and LI and PW numbers varied by instance as well as the locations of these storms, they did share a commonality that the K indices were in the mid to upper 30s. The inference can be made that with an abundance of moisture content developing tropical cyclone circulations were not well organized and subsidence was not a factor. Furthermore that the existing environment over Florida was moist and given favorable upper level conditions these systems were able to develop and as they did interactions with the developing feeder bands and the ambient sea breeze circulations were able to enhance lightning activity.

Exploring the data to support Hypothesis 3, thoughts were with more subsidence and the left quadrant of a tropical cyclone that those passing off the Atlantic coast east of Florida would produce fewer instances of

Level 3 and higher lightning. Looking back at the data, that wasn't necessarily the case. Fewer tropical cyclones were noted with 5 of 17 tropical cyclones passing off the east coast of Florida. However these 5 tied for the highest percentage of Level 3 and higher instances at 41% with those that tracked through the Gulf. These instances included Levels 3-5 lightning storms with 58% of these being Level 3 intensity, 37% Level 4 and the 5% Level 5. While the vast majority of the Gulf systems featured a southerly 850 hPA flow, these Atlantic systems mostly contained a westerly component to the 850 hPA flow except in 4 instances. It has been found in the regions in the eastern half of the state that a westerly component of the steering flow produces more Level 3 and higher lightning instances with the southwest flow providing the highest percentage of these storms (Smith, 2015). This is largely due to the placement of the Atlantic sea breeze remaining over the eastern regions of the state acting as a trigger and a lane for lightning to develop on. Also this westerly component of the wind can allow for the Gulf sea breeze and the Lake Okeechobee breeze as well as smaller lake and river boundaries over the interior portion of the state to converge with the Atlantic sea breeze which given ideal conditions with respect to instability and moisture levels can enhance lightning storms and cause issues to the energy territory covered which in this case covers almost the entire east coast of Florida. These boundaries with interactions from the outer feeder bands from these Atlantic tracking tropical cyclones have led to this percentage of lightning instances despite fewer tropical cyclones compared to the Gulf side. But another reason is that these tropical cyclones passing to the east have had their feeder bands slash into a moist environment over the state. 74% of these instances featured PWs over 2 inches and all instances featured K indices at 30 and higher. So even with a track that would normally promote a subsidence and drier setup over Florida these took advantage of an environment with more than adequate moisture for impactful lightning storms.

Molinari et. al found that lightning flash density was at a minimum in a 100 km region away from the eyewall in a tropical cyclone (1999). This area in a tropical cyclone is more stratiform in nature with heavier banded precipitation though with relatively weak updrafts compared to outer bands, lightning activity is kept down in comparison to outer feeder bands where there are more breaks in clouds and it is more unstable (Molinari, et. al, 1999). In observing tropical cyclones and their lightning patterns, these theories seem to verify and with the tropical cyclones in this study that was largely the case as well. The inner core of six tropical cyclones directly impacted the Florida energy client's territory. Level 3 and higher lightning instances occurred only one time in one tropical cyclone, Barry in 2007, which was in a weakening phase and actually becoming extratropical (Nhc.noaa.gov, 2007). Tropical Depression Barry produced an instance of Level 3 lightning on the southern side of its circulation over St. Johns County. Figure 4 is a screen capture of the radar at the time with the Level 3 in question occurring within the cell south of Jacksonville.

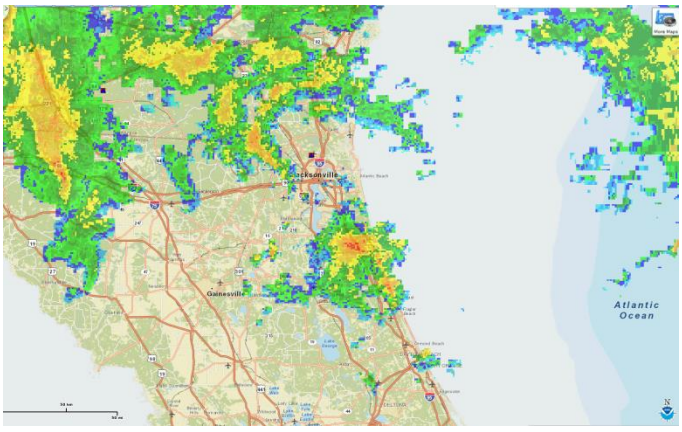


**Figure 4:** *NEXRAD Level III data at 2230Z on June 2, 2007 (Gis.ncdc.noaa.gov, 2015). The last National Hurricane Center advisory on Tropical Depression Barry was issued at*

*2100Z locating the poorly defined center near Jacksonville.*

This can be argued however as the lightning storm was somewhat detached from the inner core of the circulation which was open on its southeastern side. The storm was within 100 km of the center though the structures of tropical cyclones vary and there can be an argument on what is defined as an inner core especially in poorly developed or weakening systems like this.

Tropical Storms Fay and Beryl both made landfall in Florida and both contained the highest number of Level 3 and higher lightning instances at seven. But those instances occurred in feeder bands away from the inner core for both storms. In fact within the inner cores for those storms, lightning strikes were few. The outer feeder bands contained the vast majority of the total lightning strike activity. These occurred in advance of landfall, while the center of circulation was over the state and also as much as five days after the initial direct impact.

Considering the pattern of lightning within tropical cyclones, the thought is that where tropical storm and hurricane advisories were issued would be where there would be a minimum of Level 3 and higher instances. The thought would be that the tentacles of these feeder bands and their higher lightning would reach far away from areas under an evolving or imminent threat. The data found mostly supports this when it comes to Hypothesis 4. 54% of the Level 3 and higher lightning instances occurred when there was not a tropical storm and/or hurricane watch/warning in place anywhere. Only 2 of the 46 Level 3 and higher instances, covering 4% of all instances, occurred within an area that was under a tropical storm and/or hurricane watch/warning. Those 2 instances, both at Level 3 intensity, both happened in the East region with a tropical storm warning in place both times covering Tropical Storm Fay and Tropical Storm Isaac. Isaac never moved inland over the Florida Peninsula and Fay zigzagged its way northward across the state with this instance occurring one day before it moved inland. Both instances occurred in outer feeder bands in an environment with PW values at or above 2.30 inches, K indices at least at 33.9 and LI's between -4 to -5 with 850 hPA speeds at or above 20 knots out of the southeast. So a very moist and unstable environment was in place for these feeder bands to collect lightning. The impacts to planning especially when it comes to utilities will be discussed further.

Relating the tropical cyclone Level 3 and higher instances with those kinds of lightning storms otherwise seen in Florida was thought to feature a setup where the low level flow was stronger yet more moist and unstable than the mean. From January 2007-April 2012 there were 1257 instances total of Level 3 and higher lightning within the Florida energy client's territory. The sample size is very small when it is broken into the tropical cyclone influenced instances, coming in around 3.7% of that figure. The correlations between 850 hPA wind speeds, LI, PW and K index values are small on a whole as well and the results are kind of mixed when it comes to the idea behind Hypothesis 5. Figure 5 shows the closeness of these values.

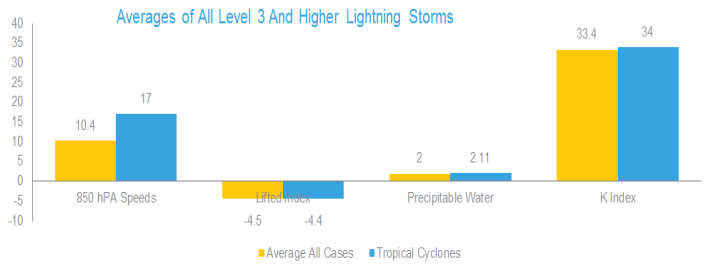


**Figure 5:** *Averages of all Level 3 and higher lightning storms compared to those averages during tropical cyclones.*

Understandably tropical cyclone low level speeds will be higher than what is typically the case. Then the instability and moisture values are not too far apart. Especially with the lifted index showing that the average of all cases was more unstable by a miniscule amount than with tropical cyclones. All of the tropical cyclone instances featured LI's below 0 while for other cases, there were some with positive LI values. So it was unstable for these tropical cyclone feeder bands to produce these Level 3 and higher lightning instances but with more non-tropical cyclone instances the numbers come in close. Despite the fact that 35% of the tropical cyclone instances featured PW values under 2 inches, the more moist numbers were fairly high, going at or over 2.60 inches in 3 instances or 6.5% of the instances and this makes sense given the atmosphere in place in association with tropical cyclones. 6.5% or 3 instances of the tropical cyclone instances featured a K index under 30.0. But compared to all other cases, the average for tropical cyclones is just 0.6 higher. 35% of the K index values were at or over 35.0 for tropical cyclones so a majority clustered in the 30.0-34.9 range. Moisture depth does not have to be excessive for these Level 3 and higher storms to occur. In fact there is an argument that higher K index values were noted where there were not Level 3 and higher storms within the inner core of the tropical cyclones given its typical vertical moisture profile.

Breaking the numbers down by directional 850 hPA flow has shown more variance in the variables between tropical cyclone Level 3 and higher lightning storms and all Level 3 and higher lightning storms as displayed in Figure 6.

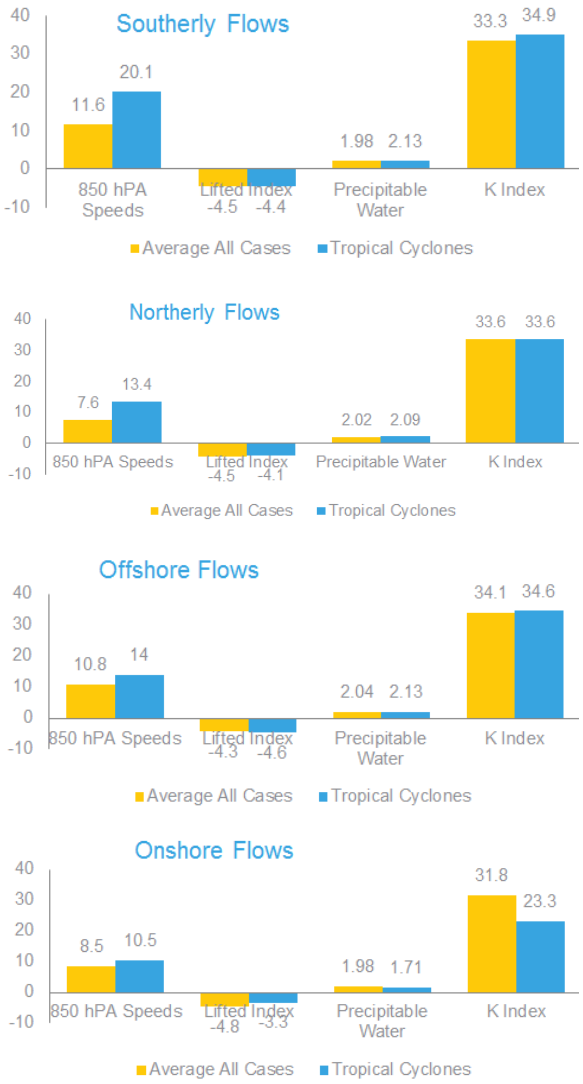


**Figure 6:** *Comparisons based on Southerly, Northerly, Offshore and Onshore 850 hPA flow regimes between all Level 3 and higher lightning storms and those involving tropical cyclones.*

These averages follow closely to what the overall numbers compare to with each flow in that the 850 hPA speeds are higher, PW's are higher, and K indices and LI's differ marginally. The 850 hPA onshore flow setup did go against the mean for instability and moisture levels. There were two instances of onshore flow with respect to Level 3 and higher lightning storms associated with tropical cyclones and the moisture levels are most notable with both featuring PW's under

1.85 inch and K values at 27 or lower. These both occurred on the very outer fringes as well with one instance in the West region off Tropical Storm Beryl which was over north Florida and the other instance in the East region well away from Tropical Depression 5 which was south of the Emerald Coast off the Florida Panhandle. With the lower than what is typical moisture levels it is reasonable to project that some subsidence had worked in over both instances and that the lightning activity was a matter of not only the very outer fringe bands but also a convergence of surface boundaries which was described in the review of the instance involving Tropical Depression 5 which did turn out to be a Level 4 lightning storm. It is assumed that with onshore flow 850 hPA setups that it is more likely to produce Level 3 and higher lightning when the tropical cyclone is further away from a location than with any other flow regime and also that moisture levels lower than what is usually expected due in part to subsidence is what one should look for.

Not all 850 hPA flows provide the same results when it comes to what is typical for Level 3 and higher storms for each region in the Florida energy client's territory. Some observations from these tropical cyclone lightning storms compared to all Level 3 and higher storms were made for each region in the following:

**North (North/Central Florida broken down from Seminole and Volusia counties north):**

All but one instance of tropical cyclone Level 3 and higher lightning in North and Central Florida featured 850 hPA wind speeds stronger than the averages with that being one of the instances with Fay which was located over the central Gulf. This suggests that this part of the region that dealt with Level 3 and higher lightning was on the periphery of tropical cyclones and was able to tap into stronger upper westerly flow. The strongest flow was one that featured 51 knot southwesterly 850 hPA flow and that was with Olga and that was the strongest overall southwest 850 hPA flow for a Level 3 and higher lightning case in this part of the region besting the overall average by 34 knots. The strongest overall Level 4 instance in a northwest 850 hPA flow was 26 knots from Arthur in Palatka with Arthur at that point off the South Carolina coast. Even with these tropical cyclones well to the north there have still been cases of Level 3 or higher lightning out of them in this part of the region. There were instances that produced higher instabilities with lower LI's than the average. Notable exceptions include Olga, also Barry and the Arthur case. With that only the Barry case produced higher PW's than the average otherwise those cases with lower instability had lower PW's. The same can be said for the K index values with only the Level 3 and higher instance with Barry showcasing a higher K index than average than the Olga and Arthur situations. With Olga, Barry and Arthur, the impacts for Level 3 and higher lightning occurred more with frontal systems or outer fringe bands. But there were even lower K index values than average in one of the Fay instances with that producing 850 hPA speeds at 5 knots less than average flow in a southerly 850 hPA regime when Fay was over the Gulf, suggesting that its direct influence was to the west and that the sea breeze boundaries helped to trigger a Level 4 lightning storm within that outer fringe band. Instability was higher than the average in that case. Also a notable lower than average K index value and lower PW yet higher 850 hPA speed albeit with higher instability happened in the wake of Irene well to the north in Port Orange and Dorian well east of the state that was more of a fringe/sea breeze situation. The instance with Arthur, which was a Level 4 lightning storm, occurred with a lower than average K index value, higher 850 hPA speeds than average with lower instability and moisture levels than the average since the hurricane was well to the

north off the Georgia/South Carolina coast. Even with a tropical cyclone well to the north, one does not necessarily have to have enough moisture and instability and it probably would not be what is expected given its orientation in thinking that subsidence would play a role. Yet this kind of lightning was observed.

**North (Brevard south through the Treasure Coast to Martin County):**

There were not many tropical cyclone-induced Level 3 and higher instances in this part of the region. Compared to the overall averages, the strongest north-northwest and south-southeast tropical cyclone Level 3 and higher lightning instances occurred and both were in St. Lucie County. The highest PW instances compared to the overall averages occurred with southeast, south-southwest and south-southeast 850 hPA flow setups. All of the K index values were at least 30 or higher. Just two Level 4 lightning instances were observed and both involved the strongest and lightest 850 hPA flow of what was analyzed.

**East:**

The strongest instances of overall Level 3 and higher lightning storms with south and southeast 850 hPA flows were noted in tropical cyclone instances and both occurred with bands from Isaac on consecutive days. Also the highest PW for a southerly 850 hPA flow instance occurred with Isaac including one with a 51 knot 850 hPA flow. All of the Level 4 lightning instances happened when the 850 hPA flow was slower than the overall average for that direction. Two of the three Level 4 instances happened with PW's were below the overall average for that 850 hPA direction and those occurred with Tropical Depression 5 which was near the Emerald Coast and also Beryl over inland north Florida. Interestingly enough a Level 4 with southwest 850 hPA flow and a 1.4 inch PW from Beryl was the lowest PW for a Level 4 with southwest flow in the region overall. So even in a drier regime one can expect higher lightning well to the south of the circulation center.

**South:**

All of the tropical cyclone Level 3 and higher lightning instances happened with some sort of westerly 850 hPA wind component. Just one Level 4 instance occurred and that was with a “ghost” of a re-developing circulation, that being Dorian. But that was not the only one Level 3 and higher lightning instance with a developing circulation involved. No Gulf systems involved, probably because influences over this region were too far away. Amazingly, there was an instance that produced quarter size hail in an instance which occurred with a Level 3 lightning storm and that was associated with Beryl which was closing in on northeast Florida at the time. There was not a wide spread in 850 hPA wind speeds between tropical cyclone Level 3 and higher lightning instances compared to overall storms of that nature with analyzed speeds within 5 knots. 850 hPA speeds faster typically became more of a wind issue than a Level 3 and higher lightning issue looking back. All Level 3 and higher tropical cyclone lightning instances except ones with southwest 850 hPA flow featured PW’s above the average and they were solidly above the average by at least 0.23 inch. There were two instances where the PW's were below average were all were below 2.00 inch PW; one was the Beryl instance and the other from Andrea which was post-tropical in southeastern Virginia and this was the same with regards to the K index values.

**West:**

Only one tropical cyclone Level 3 and higher lightning instance featured an LI that was more unstable than the overall average for that 850 hPA wind flow and that was the Lee instance with a front being involved. There were two instances where the PW’s were lower than the overall average and these

occurred in two northerly 850 hPA flow setups, both involving Arthur. Yet despite this, these instances occurred in outer fringe bands that produced Level 4 lightning.

## 5. ENERGY IMPACT

Exactly numbers on the energy interruption in Florida from lightning due to tropical cyclones are difficult to find but it is known that lightning and tropical cyclones contribute to a large number of power outages. Lightning being a hidden danger for utility companies can get buried in the details when it comes to actual outage numbers and costs and times for restoration compared to other hazards from tropical cyclones. According to the Florida Energy Sector Risk Profile, the leading weather cause for transmission outages were from hurricanes and tropical systems from 1992-2009 (State of Florida Energy Sector Risk Profile, 2014). Also from this report, Weather/Falling Trees contributed to more of the electric outages in Florida from 2008-2013 with average time being without electricity during this period amounting to 65.6 hours per year (State of Florida Energy Sector Risk Profile, 2014). The main reason for power outages and short term power flickers in our Florida energy client's territory is due to the impacts vegetation plays on their equipment and power lines (Electric Energy Online, 2015). The causes for these power flickers vary but weather related factors including lightning along with winds blowing tree branches and palm fronds onto power lines as well as salt water spray are important (Fpl.com, 2015). These can be heightened with tropical cyclones and those that produce Level 3 and higher lightning. Power outage statistics are unavailable for this paper based on what would be expected by the level of lightning but the thinking is that energy interruptions do not increase linearly with each increase in level of lightning but it can be more of an exponential rise though this depends on where the lightning storm does occur and the extent of the power equipment, i.e. if power lines are buried or over ground.

There were a couple of vague power outage numbers in areas involving Level 3 and higher lightning instances that occurred from the tropical cyclones analyzed. There were 241 customers out of power at one point following a Level 3 lightning storm in St. Johns County from Barry (Pakkala, 2007). Around 1,300 customers lost power from a Level 3 lightning storm in Palm Beach County though at the time there were tornadoes reported in the county that could have contributed to this figure (Palmbeachpost.com, 2012). It is not entirely clear whether lightning was the sole cause for these outages. The impacts of wind and water can "cloud" overall outage figures from tropical cyclones as well so it is unclear in other tropical cyclones analyzed what outages were directly caused or influenced by lightning, especially at Level 3 and higher intensity.

In a specific case, Schneider Electric meteorologists noted power outages in real time from a Level 5 lightning storm that impacted the West region ahead of a tropical depression that would soon become Tropical Storm Bret. 387 lightning strikes in a 5 X 5 km grid were noted at the peak. The power tracker showed between 2-100 customers impacted by the storm along and east of I-75 in the Naples area which given the intensity of the lightning seems like a low number of outages. But like was stated above, just because there is a high level of lightning and this storm was one level from the top of the scale, does not mean that actual outages would be astronomical. The location of this particular storm on a feeder band appeared to be in an area with lower population density as opposed to areas west of I-75 within the city of Naples. Within this feeder band a Level 4 lightning storm developed in Fort Myers. This impacted the city from I-75 westward producing several outages between 2-100 customers affected

but also an area where 101-500 customers were impacted. It was unknown how many lightning strikes were in a 5 X 5 km grid for this storm. The total number of customers impacted from these two lightning storms was unknown as well.

## 6. SUGGESTIONS FOR ENERGY ASSESSMENT PLANS

A weather readiness assessment plan for utilities when it comes to tropical cyclones should cover hazards from lightning as well. From the analysis it was found that Level 3 and higher lightning storms occurred up to 3 days before and up to 5 days after a direct landfall from a tropical cyclone in the Florida energy client's territory. Plans may not directly cover the impacts lightning has on the electric grid especially in a tropical cyclone's formative state. Also some may not have plans for tropical cyclones activated until the National Hurricane Center issues a tropical storm and/or hurricane watch or warning. Even areas not within an advisory, Level 3 and lightning instances occur and from above, only 4% of the instances analyzed occurred in advisory areas. These lightning instances know no advisory bounds with the average distance in Level 3 and lightning instances to tropical storm/hurricane advisory areas being at 389.8 km. Even after the advisory is issued, these cover the impact for winds within tropical storm or hurricane force and not lightning which reaches far from the core of the system and this should be accounted for in storm preparations.

The use of contracted and mutual assisted crews before a storm can be helpful in managing outages. Wanik, et. al wrote on a utility in the Northeast U.S. running an outage model predicting their storm outage restoration duration. This takes into account the ratio of storm outages to the average number of crews' times the outage crew fix rate based on weather parameters expected to occur in a major storm to predict how long before the vast majority of customers' power would be back on line (Wanik, et. al, n.d.). Incorporating lightning information with this can be of assistance in determining how long native and non-native crews can be expected to be on restoration duty in addition to other weather variables. This can improve the model especially knowing that lightning impacts occurs longer than the strongest winds and can spread farther in scope. The limitations of this outage model go along with the limitations of the weather forecast however (Wanik, et. al, n.d.).

The effects of lightning may not be expressed in hurricane modeling programs for utilities in the pre-season since winds primarily do most of the damage to the power grid. In Florida where lightning and tropical cyclones are problems, the needs to mitigate outages must include lightning being a part of the plan before the tropical season and before the event. While it does not appear to be a major cause for outages, at least lightning can be an "annoyance" yet not totally detached from the even indirect impacts from tropical cyclones.

## 7. THEOREM

Tropical cyclone feeder bands produce more lightning within the tropical cyclone impacting Florida days ahead and after impacts whether directly or indirectly. These higher lightning instances can hamper restoration and aggravate pre-planning ahead of tropical cyclones for utilities.

## 8. CONCLUSION

When it comes to tropical cyclones, a hazard that should not be overlooked in a state that deals with them more than just about anywhere else in the world is lightning. Issues to utilities perhaps unforeseen can and has happened in moderate and higher lightning storms within feeder bands that may not be near where the core of a tropical cyclone is. Certain tropical cyclone tracks can produce more

lightning than others and even in formative stages and when they are moving out, outer edge bands can bring at times high to excessive amounts of lightning. Even with a faster low level flow compared to other impactful lightning events, these moderate and higher lightning events do happen with tropical cyclones especially within a moist and unstable environment and can be influenced by low level boundaries. Knowledge of these lightning patterns can help in preparation for utilities in planning for these hazards in addition to wind and water impacts.

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