INVESTIGATING THE SPATIAL AND TEMPORAL EVOLUTION OF LIGHTNING IN PRE-DEPRESSIONS IDA (2021) AND IDALIA (2023) USING THE GEOSTATIONARY LIGHTNING MAPPER

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1. INTRODUCTION

While recent work has contributed to a better understanding of the relationship between lightning and tropical cyclone intensity change, there is a lack of understanding for the relationship between lightning and tropical cyclogenesis. Previous research has mainly used land-based detection networks to investigate developed systems, with the goal of using lightning as a potential indicator for intensification or weakening. Few studies have attempted to examine lightning in pre-genesis disturbances, and these studies have yielded conflicting results (e.g., Leary and Ritchie 2009 and Leppert et al. 2013b). This study introduces a novel approach to the problem of forecasting tropical cyclone genesis by using the Geostationary Lightning Mapper (GLM) on the newest generation of GOES satellites to examine lightning attributes and trends prior to genesis.

Lightning is often used as a proxy for deep convection, which has been suggested as a possible identifier for tropical cyclone genesis. Bruning and MacGorman (2013) and Duran et al. (2021) have found that lightning and its varying characteristics, such as frequency, energy density, and area, were indicative of different precipitation modes, such as deep convection. Specifically, deep convective regions were often characterized by frequent, small, low-energy flashes, while stratiform regions feature less frequent, larger, and more energetic flashes. Previous work has shown that higher fractional coverage of deep convection, defined by cold IR brightness temperatures, was an effective predictor of genesis (Leppert et al. 2013a,b; Zawislak 2020). However, when relating lightning to genesis directly, results have conflicted. In looking at eastern North Pacific tropical disturbances, Leary and Ritchie (2009) used land-based detection networks and found systems that developed had a considerably larger quantity of lightning flashes than non-developers. Using the spaceborne Lightning Imaging Sensor, Leppert et al. (2013b) concluded that lightning flash rates and other indicators of convective intensity showed no differences between Atlantic developing and non-developing waves. These discrepancies motivate the current study to investigate lightning from GLM in pre-genesis disturbances.

2. METHODS

2.1. Case Studies

Ida (2021) and Idalia (2023) were selected as case studies for this analysis due to various similarities in their pre-genesis setup. Both systems tracked near land in the days leading up to genesis and became tropical depressions in the western Caribbean Sea in late August. Additionally, forecasting genesis location and time for both of these systems proved to be difficult.

As stated in Ida's postseason Tropical Cyclone Report, its genesis was somewhat poorly forecasted (Beven et al. 2022). While forecasts correctly predicted genesis in the southwestern Caribbean Sea, Ida formed much sooner than expected. The National Hurricane Center (NHC) Tropical Weather Outlook (TWO) 5-day formation probabilities were raised to the high category (>60%) only 30 hours prior to genesis, and 2-day probabilities were raised to the high category only 6 hours before genesis.

Similarly, Idalia formed sooner than expected as the NHC TWO 2-day genesis probabilities failed to reach the high category prior to genesis (Cangialosi and Alaka 2024). Forecasting the location of genesis for Idalia also proved to be challenging as the system formed farther offshore than expected, impacting its intensity forecast as it later threatened the Gulf Coast.

2.2. Geostationary Lightning Mapper

The GLM is a near-infrared optical transient detector with the ability to map lightning at very fine spatial and temporal resolutions. These high-resolution outputs include location, area, and energy for lightning groups. A lightning group is defined as one or more adjacent pixels meeting the detection threshold in a 2 ms time period (Goodman et al. 2012). For the purposes of this project, GLM outputs were resampled onto a 2 x 2 km uniform grid to enable further analysis and for comparison with the Advanced Baseline Imager (ABI) and reanalysis outputs. GLM outputs were also grouped into five-minute intervals to streamline computational efficiency while still capturing the shorter, convective time scale of lightning.

2.3. TOBAC - Tracking and Object-Based Analysis of Clouds

TOBAC, or the Tracking and Object-Based Analysis of Clouds, was used to further characterize lightning in the context of TC genesis (Heikenfeld et al. 2019). Using TOBAC, lightning activity and cloud top temperatures were

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identified and tracked over time, enabling the ability to relate spatial and temporal characteristics (e.g., lightning feature lifetime, distance to storm center) to genesis.

The feature detection and tracking functions for TOBAC were guided by various input parameters determined by the user. To optimize these parameters for the time and spatial constraints of the ABI and GLM data, a sensitivity analysis was conducted to gauge the suite of input parameters that identified and tracked lightning in a manner that best reflected reality and physical intuition.

2.4. Wave Tracking

Official tracking of tropical disturbances by the National Hurricane Center begins with the declaration of an area of investigation, which typically occurs only a few days before genesis and may be several days after satellite imagery can identify the disturbance. To extend the pregenesis analysis period, multiple track sources were combined into a single file that included a suite of storm and environmental variables. Two of the track sources included the Automated Tropical Cyclone Forecasting System b-deck for the invest and named storm. The third track source was created by advecting the first position in the invest b-deck backward in time using the shallow layer beta and advection model (TABS; DeMaria et al. 2022), which used ECMWF 5th Generation reanalysis (ERA5) fields. Combining these three sources allowed for analysis of a tropical disturbance multiple days before genesis. The tracks and their associated variables were then linearly interpolated by five minutes to match the time step used to process the GLM data. These interpolated outputs were used to introduce various frameworks of analysis that related lightning to factors such as shear, storm motion, and storm center.

3. PRELIMINARY RESULTS AND DISCUSSION

3.1. Characterizing Lightning Activity Over Time

Total optical energy, defined as the sum of lightning energy of all pixels in a specified radius, was used as a high-level indicator of lightning activity in Ida and Idalia. A radius of 500 km was used to analyze lightning activity in the disturbances and their environment. To focus on internally-forced lightning, a filter was used to remove lightning over land that may have resulted from proximity and interaction with land. As shown in Figure 1a, total lightning energy over water and within 500 km of the storm center was found to spike within a day of genesis. This spike coincided with a similar jump in total lightning group count for both Ida (Fig. 1b) and Idalia (Fig. 1c).

Previous work has suggested that the increase in total energy and group count shown below could be attributed to the presence of small and intense convective updrafts, which are characterized by frequent, small, and low-energy flashes. However, when mean group area and energy (not shown) in Ida and Idalia were examined via a similar time series, the results conflicted with this hypothesis. The mean group energy remained constant before and after genesis for both storms, while the mean group area spiked right before genesis. A constant mean group energy would suggest a constant ratio or presence of deep convective and stratiform regions. However, an increase in the mean group area would be indicative of an increase in stratiform regions. The discrepancy between the hypothesized precipitation mode and those indicated by the mean group area and energy is likely due to averaging the mean group area and energy per pixel over the entire analysis region. As a solution, TOBAC will be used to track these values for each individual feature, helping to better represent these group statistics over time.

3.2. Identifying and Tracking Lightning Features Using TOBAC

In order to facilitate an in-depth spatial and temporal analysis, TOBAC was used to identify and track lightning features over time. Figure 2a illustrates the abundance of tracks of lightning features on August 25, 2021, a day before Tropical Depression 9 (Ida) formed. The varying length of tracks near the center of the disturbance and its surrounding environment introduces questions about how longer-lasting lightning features may be related to genesis as opposed to shorter-lived ones. The high density of tracks over the northern coast of South America further emphasizes the impact of land on lightning activity and the need to consider these impacts.

Figure 2b shows the underlying framework of the analysis with TOBAC, as identified lightning features and their characteristics can be related to the disturbance's center and the associated ABI cloud top temperature. Tracking characteristics such as group energy and area over time can also provide better insight into precipitation mode and how processes, such as deep convection, relate to genesis. Analyses using TOBAC will be shown and discussed further in the poster presentation.

4. SUMMARY AND CONCLUSIONS

Although past studies have focused on the relationship between lightning and tropical cyclone intensification, this is believed to be the first study to use GLM observations to explore the relationship between lightning and tropical cyclogenesis. In exploring the two case studies of Hurricane Ida (2021) and Hurricane Idalia (2023), we have found that total optical lightning energy and total lightning group count for lightning over water and within 500 km of the storm center increased within a day of genesis. Analyzing clusters of lightning activity individually using TOBAC, an algorithm used to identify and track features over time, will provide a more informative approach to gauge spatial and temporal trends in lightning and how they relate to tropical cyclone genesis. These analyses will be shown and discussed further in the poster presentation.

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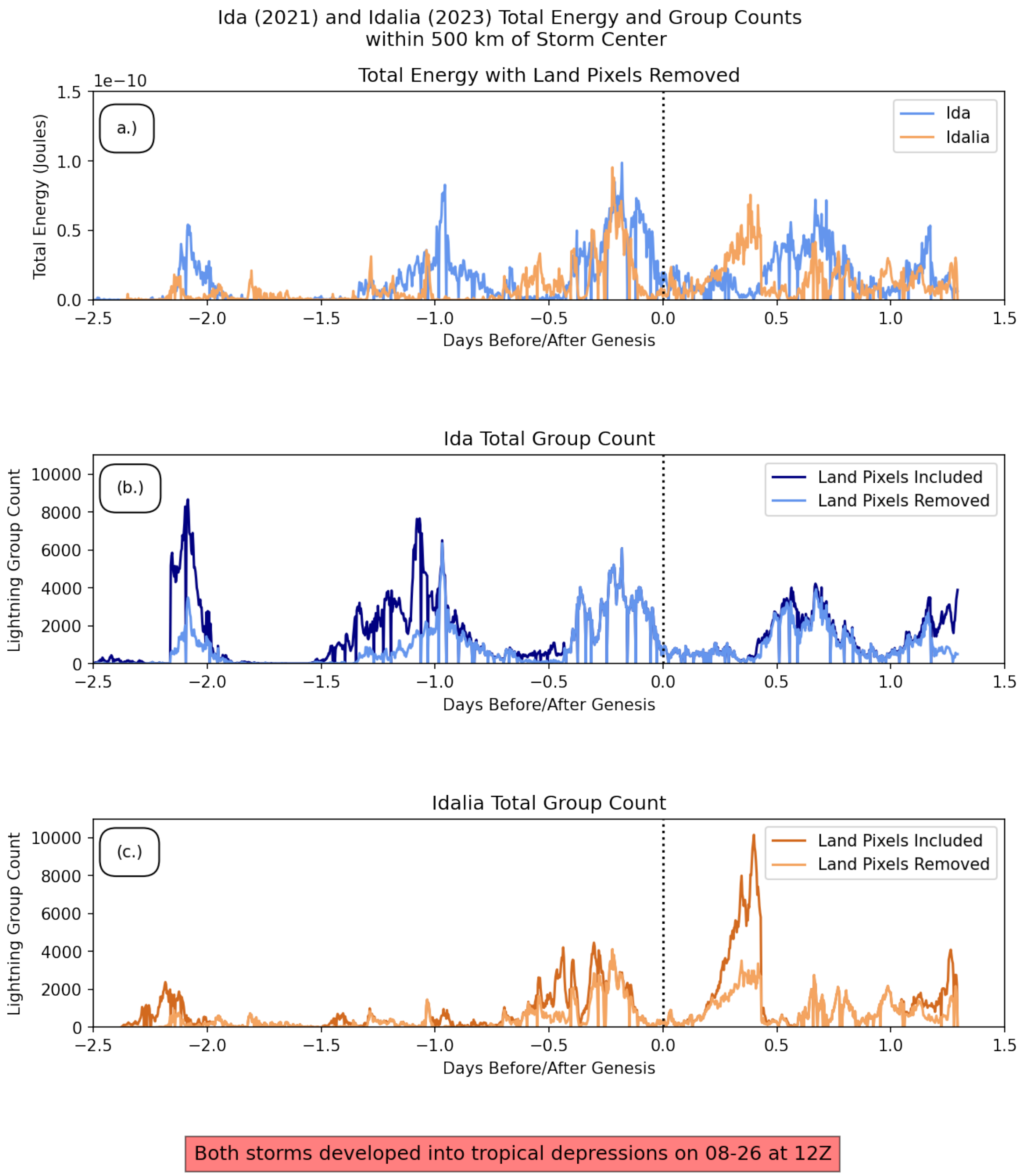

FIG. 1. Figure 1a shows total lightning energy within 500 km for Ida and Idalia with land-based pixels removed. Figures 1b and 1c show total lightning group counts within a 500 km radius of the storm center over time for Ida and Idalia, respectively. These values are shown with and without land-based pixels to account for external forcing induced by land interaction.

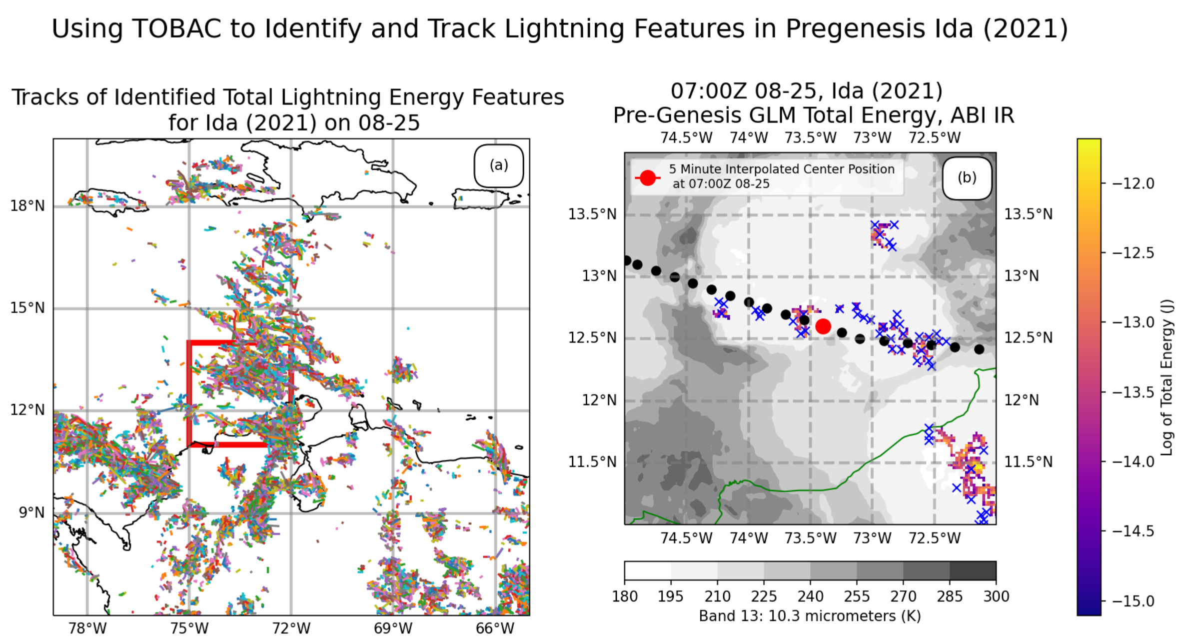

FIG. 2. Figure 2a shows the tracks of identified lightning features using TOBAC on August 25, 2021 for pregenesis Ida. Figure 2b shows total lightning energy from the GLM overlaid upon ABI brightness temperatures. "X" denotes an identified and tracked lightning feature by TOBAC. Pregenesis Ida center positions plotted from the combined track file that included the b-deck for the named storm, invest, and backwards-advected position using TABS.