Using GLM Flash Density, Flash Area, and Flash Energy to Diagnose Tropical Cyclone Structure and Intensification

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Background

- **Increased lightning in tropical cyclones (TCs) is typically associated with intensification (e.g. Molinari et al. 1999; Stevenson et al. 2014), but *significant lightning outbreaks are also observed in weakening storms* (Xu et al. 2017).**
- **The total number of lightning flashes in a TC is not always a reliable indicator of TC intensity evolution.**
  - Issues with the range and detection efficiency of ground-based networks, particularly for intracloud lightning.
  - Physical processes such as vertical wind shear can intensify asymmetric convection while also weakening the TC.
- **The commissioning of the Geostationary Lightning Mapper (GLM) aboard GOES-16 and GOES-17 marked, for the first time, the presence of an operational lightning detector in geostationary orbit.**
  - In addition to flash density (the number of flashes per unit area per unit time), GLM also provides continuous observations of flash area and total optical energy.

Objectives

- **Characterize three aspects of the evolution of Hurricane Dorian (2019) using GLM:**
  1. **Hurricane Dorian's rapid intensification leading up to its peak intensity.**
  2. **Hurricane Dorian's weakening as it approached the Bahamas.**
  3. **The diurnal cycle of Hurricane Dorian.**
- **The periods that will be analyzed here include:**
  - **Diurnal Cycles 1 and 2 (DC1 and DC2).**
    - **30 Aug. and 31 Aug.**
  - **Rapid intensification (RI).**
    - **06 UTC 31 Aug. -- 12 UTC 01 Sep.**
  - **Max intensity and rapid weakening (RW).**
    - **12 UTC 01 Sep. – 18 UTC 02 Sep.**

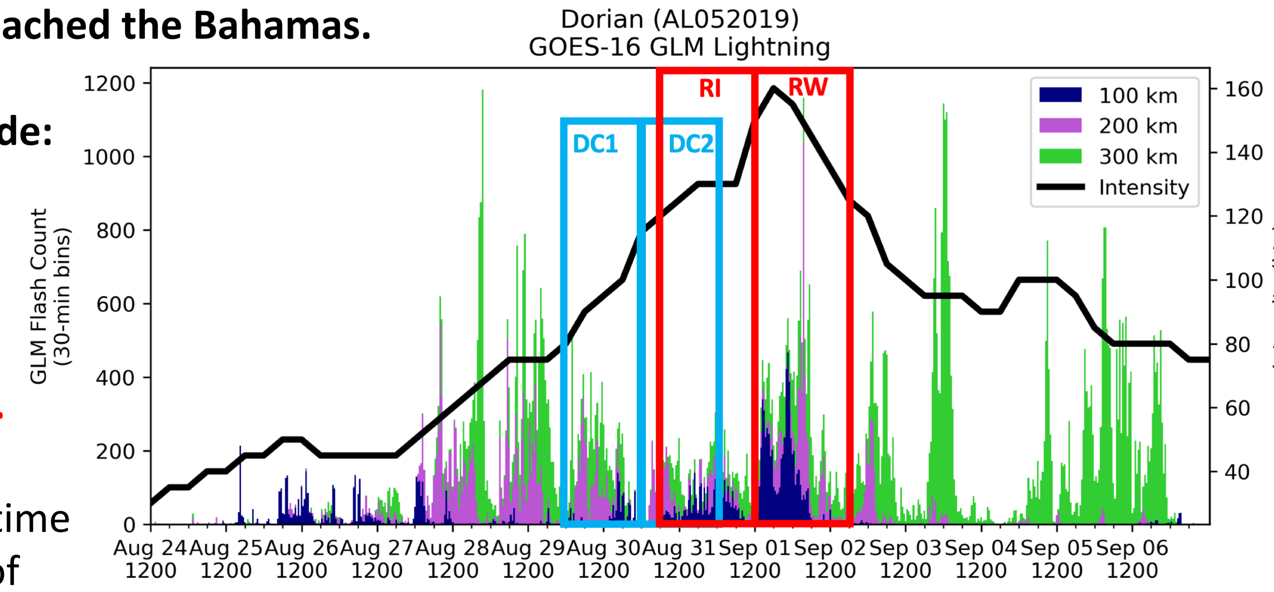


Fig. 1. GOES-16 GLM flash counts in 30-minute time periods (left axis) within 100, 200, and 300 km of Hurricane Dorian's (2019) storm center. The black line indicates the maximum wind speed (kt; right axis). The four time periods analyzed here are denoted by the blue boxes DC1, DC2 and the red boxes RI and RW, described above.

Flash Area and Flash Energy During Dorian's Rapid Intensification

- Little distinction between joint distributions for the larger domain (top row) and inner-core domain (bottom row).
  - ***No discernible difference in total optical energy or average flash area between inner core and outer radii.***
- 18,140 of the 21,351 flashes (85%) occurred within the smaller domain.
  - ***A large percentage of flashes within the storm were in the inner core.***

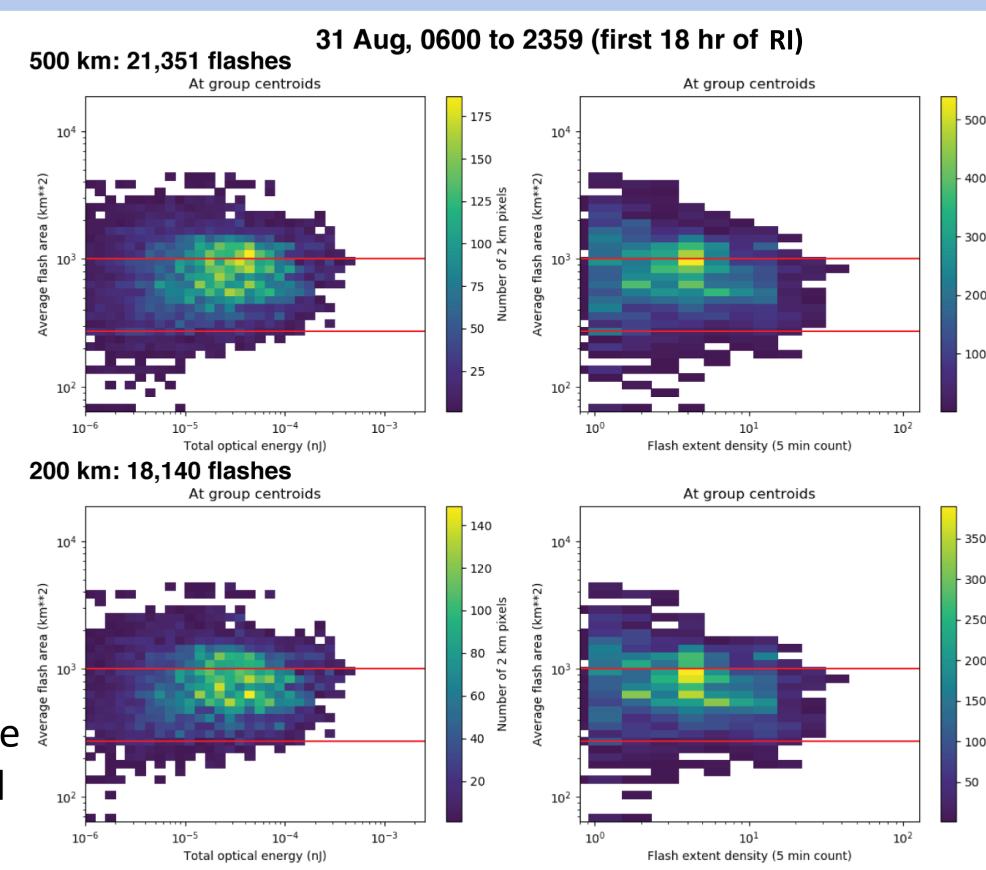


Fig. 2. Joint distributions of average flash area with total optical energy and flash extent density over a large (top row) 500-km-square domain and (bottom row) smaller 200-km x 400-km domain centered on Hurricane Dorian during the first 18 hours of the period denoted "RI" in Fig. 1. Bottom red lines denote the squared GLM group-to-flash clustering distance (16.5^2 km^2) and top red lines at 1000 km^2 are included for reference.

The Tropical Cyclone Diurnal Cycle as Observed by GLM

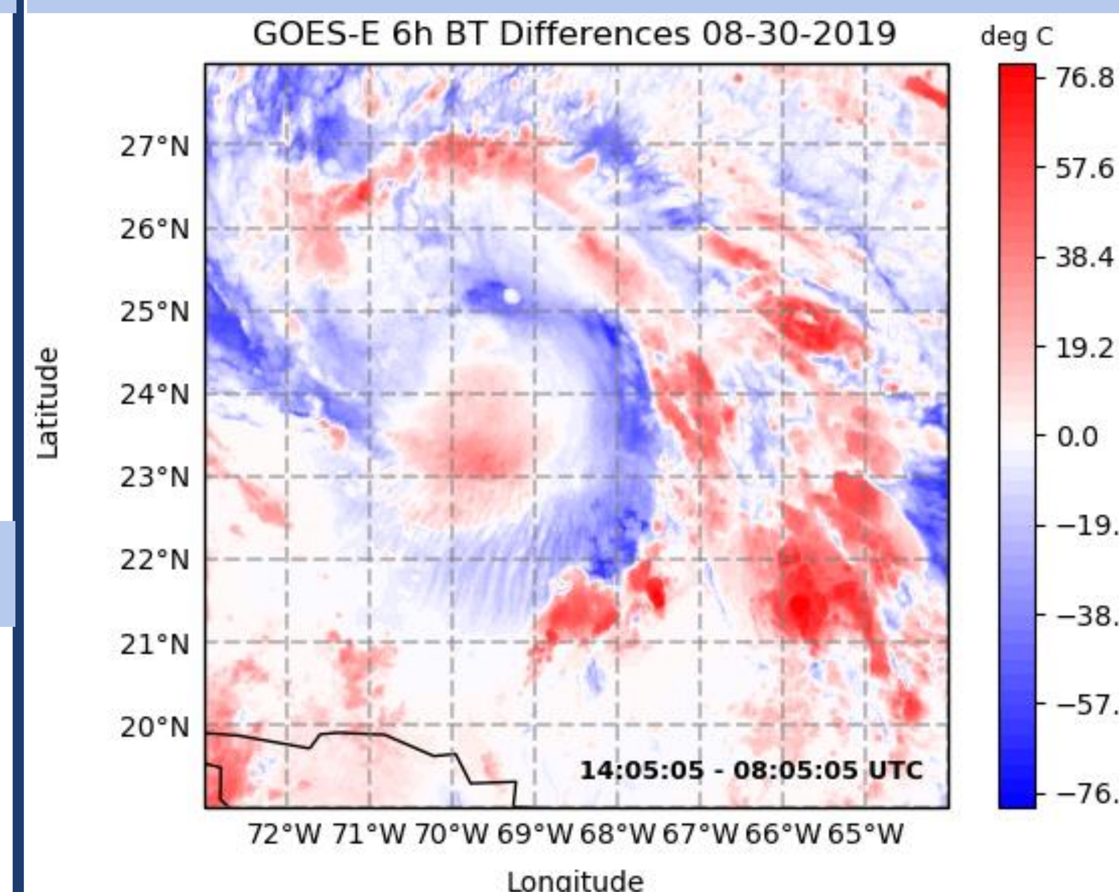


Fig. 5. GOES-16 ABI Channel 13 brightness temperature differences computed over a six-hour period. Red shading denotes warming temperatures over the 6-hour period and blue shading indicates cooling temperatures.

- Hurricane Dorian exhibited a classic "diurnal pulse" of cold cloud tops (Dunion et al. 2014).
- On both 30 and 31 August, a wave-like pulse propagated outward from the inner core, with cooling infrared brightness temperatures on the leading edge and warming infrared brightness temperatures behind (Fig. 5).

- Diurnal pulses in IR brightness temperature corresponded to outward propagating regions of lightning observed by GLM (Fig. 6).
- DC1 had more lightning at all radii, but outward propagation is evident in both DC1 and DC2.
  - ***Lightning begins in the inner core overnight, but also extended to far outer radii during DC1.***
  - ***Lightning rapidly ceases at each radius as the pulse passes by.***
- Next step: Investigate evolution of flash area and flash energy throughout diurnal cycle.

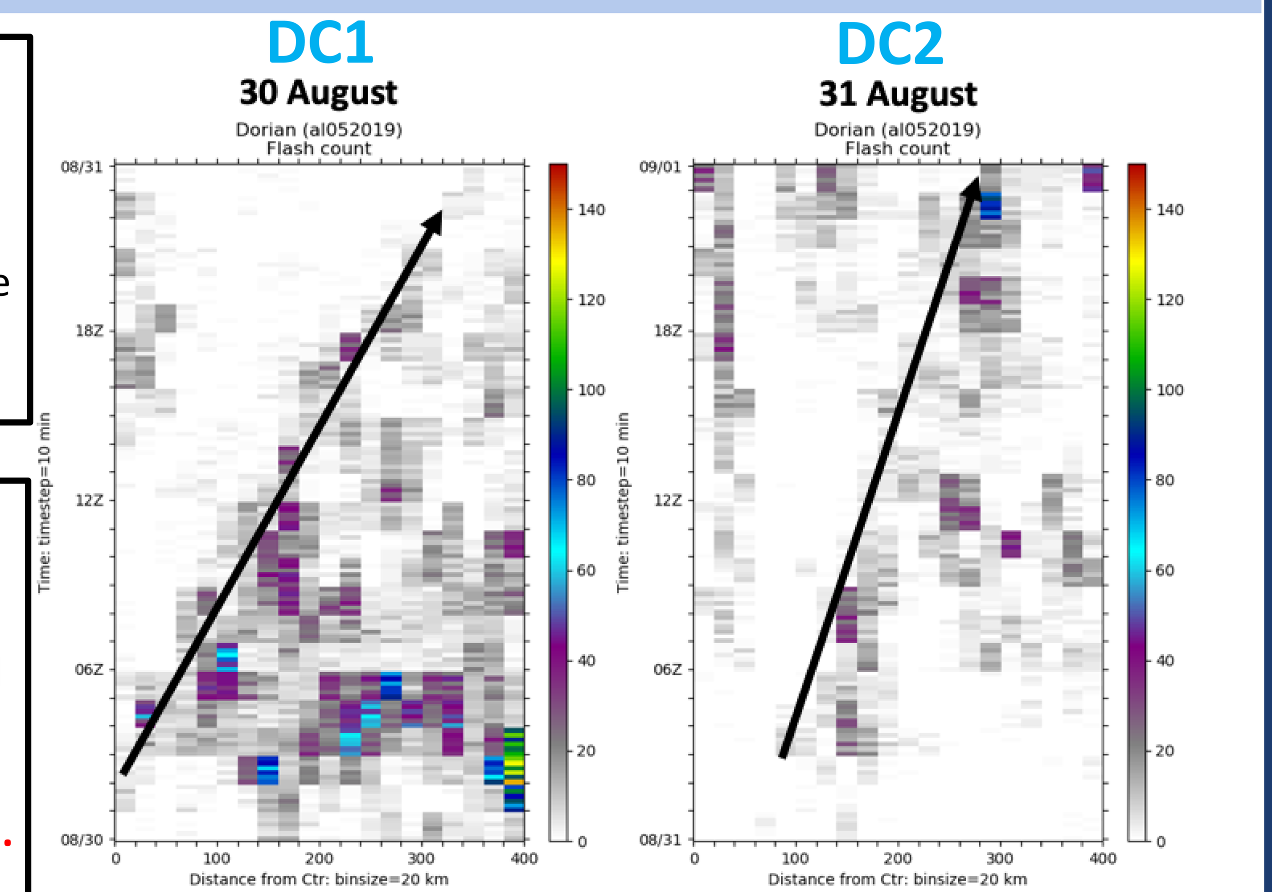
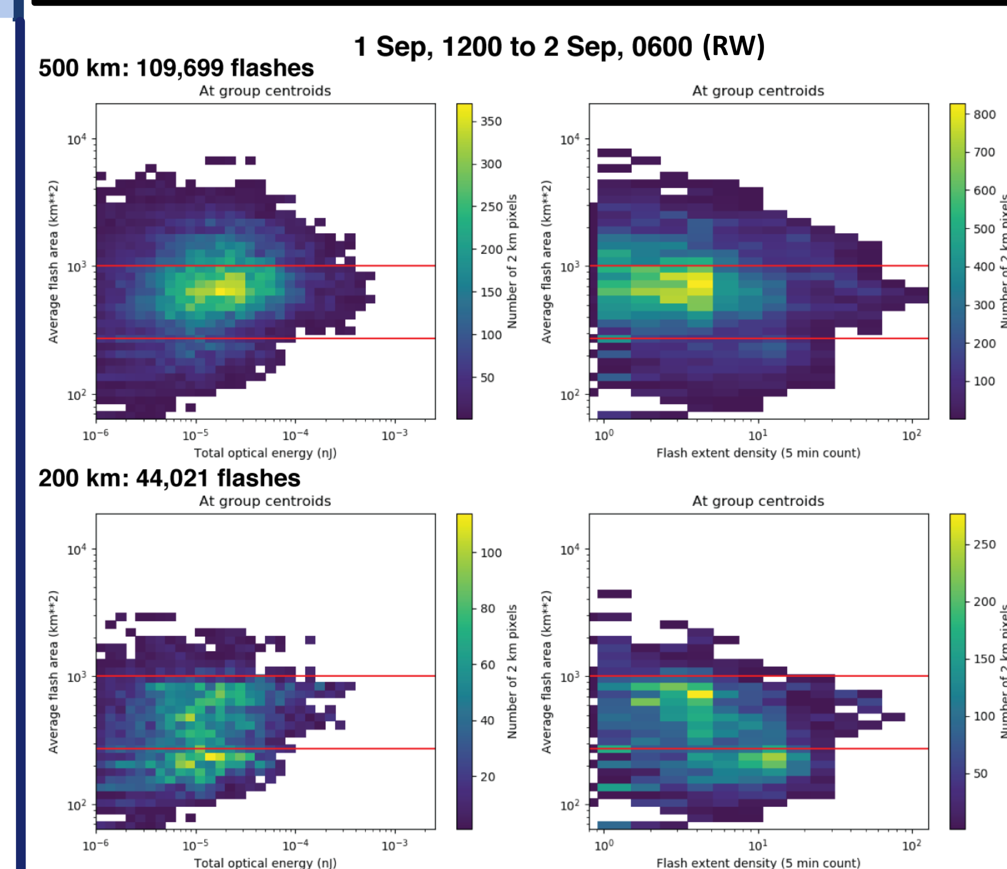


Fig. 6. Radius-time diagrams of GOES-16 GLM flash counts summed over 10-minute intervals in Hurricane Dorian for the periods indicated by "DC1" and "DC2" in Fig. 1. Black arrows denote an outward propagating region of lightning.

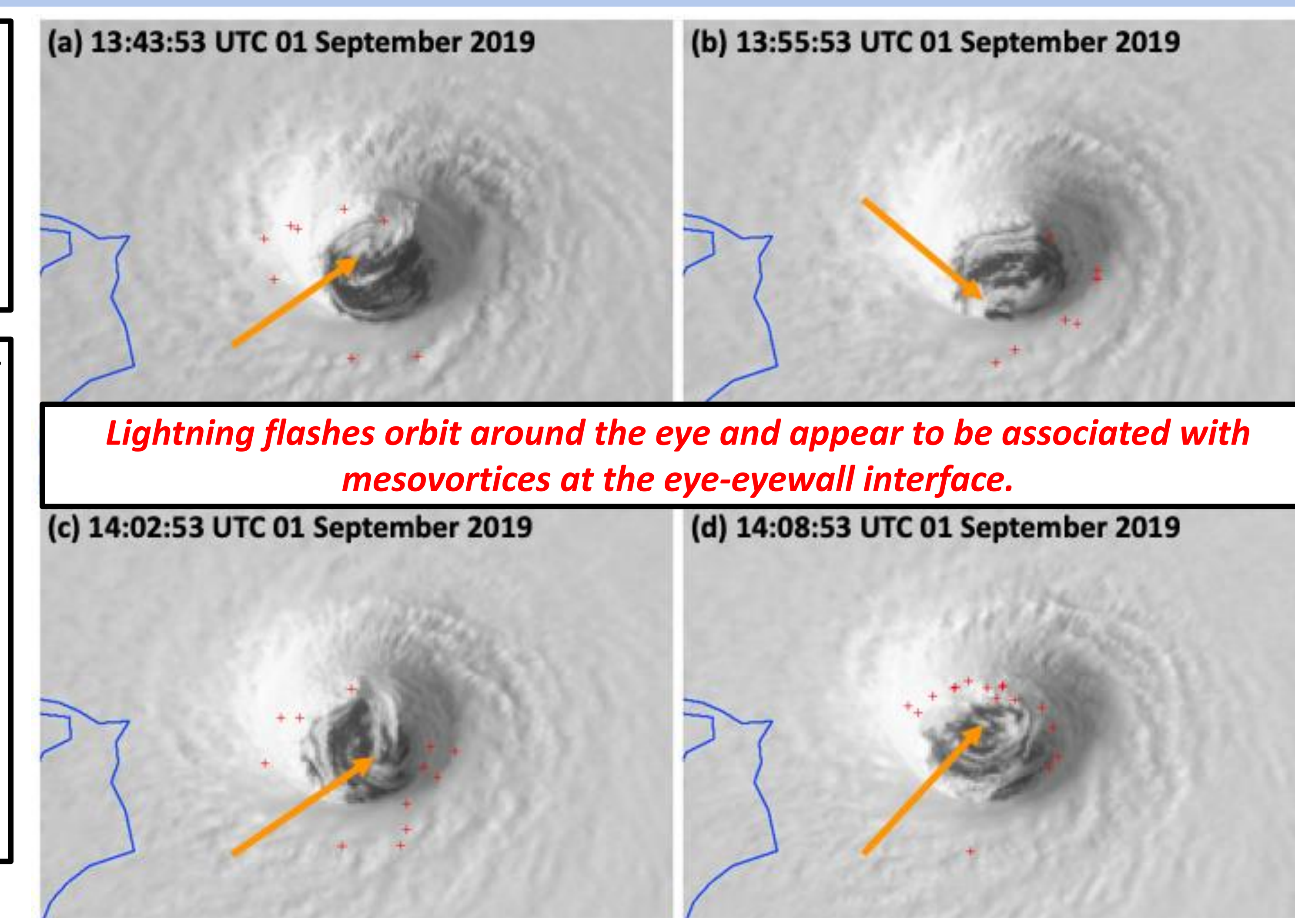
Flash Area and Flash Energy During Dorian's Rapid Weakening

- More flashes in both inner core and outer radii than during rapid intensification.
- 44,021 of the 109,699 flashes (40%) occurred within the smaller domain.
  - ***A much smaller percentage of flashes within the storm were in the inner core, compared to the RI period.***
- Considerable difference between joint distributions for the larger domain (top row) and inner-core domain (bottom row).



- Average flash area distribution for inner-core flashes is more spread out and has ***many more small flashes than during RI period***.
- Total optical energy distribution maximizes at lower values for both the 500-km and 200-km domains, and the ***inner-core energy distribution maximizes at much smaller values than during RI period.***

Fig. 3. As in Fig. 2, but for the first 18 hours of the period denoted "RW" in Fig. 1.



Lightning flashes orbit around the eye and appear to be associated with mesovortices at the eye-eyewall interface.

Fig. 4. GOES-16 ABI Channel 2 visible imagery of Hurricane Dorian with GLM flash locations (red marks) aggregated over two-minute periods centered on the time of the ABI image. Orange arrows denote the location of a mesovortex orbiting near the eye-eyewall interface.

Summary

1. Hurricane Dorian's inner core during rapid intensification was characterized by *smaller flash extent density* but *larger average flash area* and *larger total optical energy*.
2. Hurricane Dorian's inner core during rapid weakening had *many more flashes* but of *smaller average flash area* and *smaller total optical energy.*
   a) Potentially associated with enhanced localized ascent forced by mesovortices at the eye-eyewall interface, which also corresponds to barotropic breakdown of the eyewall and weakening of the TC-scale circulation.
3. Outward-propagating regions of lightning flashes in Hurricane Dorian are consistent with the tropical cyclone diurnal pulse (Dunion et al. 2014; Ditchek et al. 2019).

Future Work

1. Characterize GLM flash area and flash energy during intensification and weakening in a large number of TCs.
2. Investigate the relationship between eyewall mesovortices and lightning, and the potential to use flash area and flash energy statistics to anticipate TC intensification or weakening.
3. Analyze how flash area and flash energy change across the TC diurnal pulse.

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