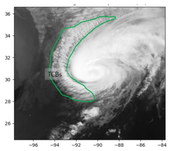
Objectively Identifying Transverse Cirrus Bands in Tropical Cyclones using a Convolutional Neural Network

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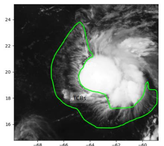
[1]University of Alabama in Huntsville, [2]Marshall Space Flight Center (Huntsville, AL)

Introduction

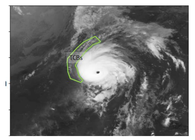
- Transverse cirrus bands (TCBs) are a phenomenon that occurs in many mesoscale and synoptic weather systems, including tropical cyclones.
- TCBs are defined as "Bands of clouds oriented perpendicular to the flow in which they are embedded" (NOAA).
- Can be associated with low static stability and high vertical wind shear in the upper levels (Kawashima 2021), along with small Rossby numbers.
- TCBs in tropical cyclones are of particular interest due to their apparent occurrence and potential linkage to the tropical cyclone diurnal cycle (Dunion et al. 2014), stronger tropical cyclones, and rapid intensification.
- To fully understand TCBs and how they relate to tropical cyclones, they must be efficiently identified using a machine-learning model.
- Miller et al. (2018) developed an image classification model that identified whether TCBs were present anywhere within a satellite image.
    - Does not provide information on the spatial structure of the bands.
- A U-Net model (Ronneberger et al. 2015) capable of image segmentation will be created to provide TCB identification and spatial information.



Example of TCBs in a tropical cyclone.



Example of TCBs in a tropical cyclone.



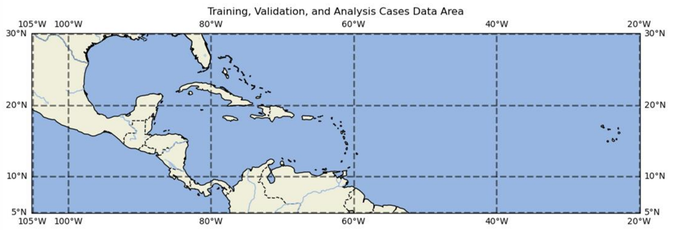
Actual training image that is not zoomed-in.

Research Questions

- Can a U-Net model be created to identify TCBs?
- Where do TCBs occur in tropical cyclones?
- What is the relation of TCBs to the tropical cyclone diurnal cycle?
    - Daily cycle of convection forming and moving outwards.
- Are TCBs related to tropical cyclone rapid intensification?
    - Intensification rate of 30 knots or more in 24 hours (NHC).
- How do TCBs relate to tropical cyclone intensity?
- Do TCBs vary based on past and future tropical cyclone intensity?
- Does the environmental wind shear affect the location of TCBs?

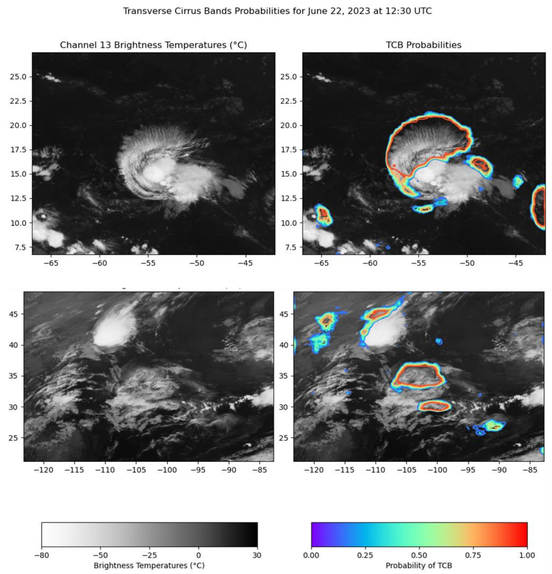
Data

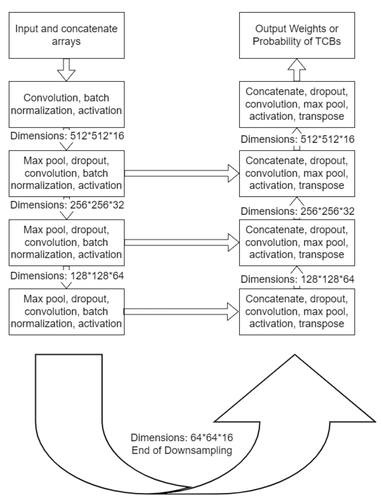
- Tropical cyclone locations are from the HURDAT2 dataset (Landsea and Franklin 2013).
- Environmental vertical wind shear over the 850-200 mb layer was obtained from the SHIPS dataset's SHDC and SDDC variables (DeMaria and Kaplan 1994).
- Geostationary Operational Environmental Satellite (GOES) 16 Advanced Baseline Imagery (ABI) data.
    - Channel 13 (Clean Infrared, 10.3 μm)
    - Channel 8 (Upper-Level Water Vapor, 6.2 μm)
- Data is contained within the area shown below.



Methods

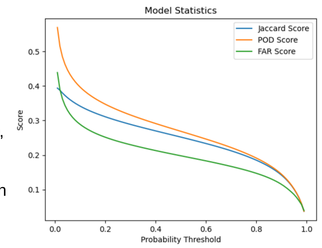
- A total of 387 training cases and 130 verification cases from 2018 Atlantic tropical cyclones
    - Images were taken every three hours throughout the lifetime of each tropical cyclone.
    - Each image was rotated three times to ensure the model does not learn TCBs occur in a particular location relative to the storm center.
- Data for channels 13 and 8 scaled to normalize the data values using the Standard Scaler.
- The U-Net was then trained until a minimum was reached in the validation weighted binary cross-entropy loss function.
    - Prevented the model from ignoring all areas due to the overall greater number of null pixels.

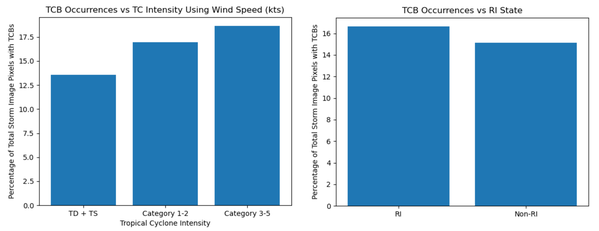




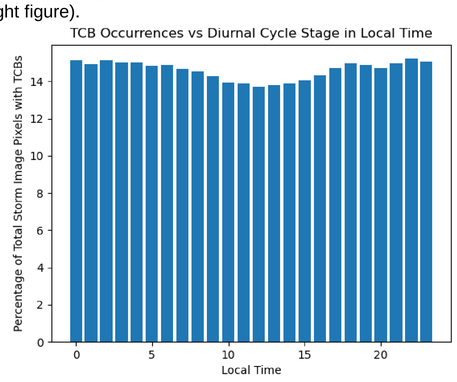
Results

- Using 351 images, a confidence threshold of 2% was to maximize the binary Jaccard (BJ) score.
    - $BJ\left(\frac{TP}{TP+FP+FN}\right)$: 38.7%
    - $POD\left(\frac{TP}{TP+FN}\right)$: 51.5%
    - $far\left(\frac{TP}{TP+FP}\right)$: 39%
- The model tends to underestimate, which lowers the Jaccard Score.
- Using the threshold, various analyses were performed based on hourly 2019 through 2023 Atlantic tropical cyclone images (8923 images).

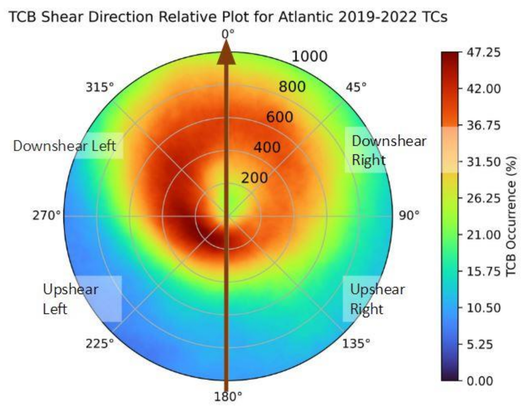




Percent of tropical cyclone images containing TCBs binned based on intensity (left figure) and whether rapid intensification was occurring (right figure).



Percent of tropical cyclone images containing TCBs binned based on the local time of day.



Percent of tropical cyclone images containing TCBs binned based on the TCB's location relative to the environmental wind shear vector.

Takeaway Points

- **TCBs appear to be related to tropical cyclone intensity.**
- **TCBs are more common in intense tropical cyclones.**
- **The downshear quadrants are favored for TCB occurrence, but TCBs are also common in the upshear quadrant.**

My Cyclone Workshop presentation can be found using the QR code provided.

Conclusions

- The created U-Net is able to identify TCBs well enough for analysis purposes and is able to provide spatial information.
- TCBs occur more often in stronger storms, especially when comparing hurricanes to tropical storms and depressions.
- TCBs appear relatively more often during rapid intensification.
- TCB activity reaches a minimum around local noon.
- TCBs occur most often in the downshear quadrants along with the upshear left quadrant.
- TCBs are more frequent at further away radii in the downshear quadrants when compared to the upshear quadrants.

Future Work

- Significance testing will be performed to see if the results are statistically significant.
- The temporal structure of TCBs will be examined.
    - Do TCBs form in the upshear right quadrant and move to the downshear right quadrant?
- More analysis of TCBs relative to past and future intensity change.
- 2024 Atlantic tropical cyclones will be added in as HURDAT and SHIPS data becomes available.

Acknowledgement and Contact

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