Unlocking GOES: A Statistical Framework for Quantifying the Evolution of Convective Structure in Tropical Cyclones

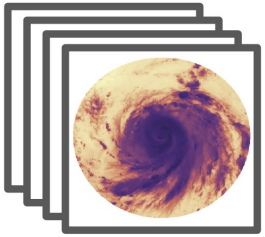
Trey McNeely[1] with Kimberly M. Wood[2], Dorit Hammerling[3], and Ann B. Lee[1]

[1]*Carnegie Mellon University, Department of Statistics and Data Science*

[2]*Mississippi State University, Department of Geosciences* [3]*Colorado School of Mines, Department of Applied Mathematics and Statistics*

Infrared (IR) imagery from geostationary satellites like GOES provides a proxy for convective strength in tropical cyclones with high spatio-temporal resolution. This information is relatively underutilized in quantitative scientific analysis and operational forecasting of TC intensity. The ORB framework provides a rich, extensible dictionary of structural functions which support the use of powerful machine learning techniques for interpretable analysis.

Data



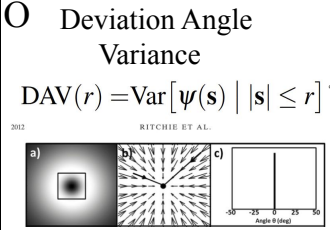
30-minute IR imagery
- GridSat GOES (previous)
- NOAA MERGIR (current)

TC Best-track data
- HURDAT2

Environmental Features
- SHIPS developmental database

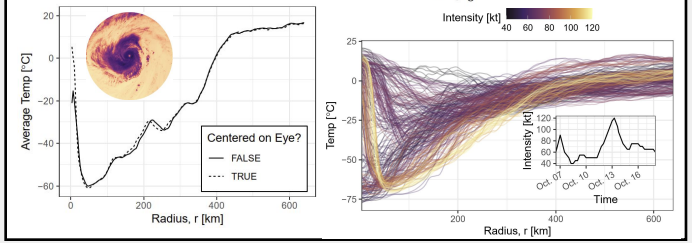
O Deviation Angle Variance

$$\mathrm{DAV}(r) = \mathrm{Var}\left[\psi(\mathbf{s}) \;\middle|\; |\mathbf{s}| \le r\right]$$



R Radial Profiles

$$\overline{T}(r) = \frac{1}{2\pi}\int_0^{2\pi} T_b(r,\theta)\,d\theta$$



ORB functions

- Organization - Radial structure - Bulk morphology -

ORB coefficients

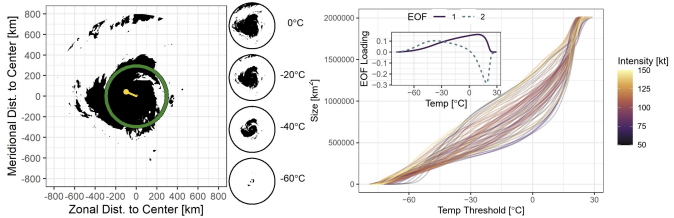
- PCA-derived functional linear basis

$$f(x) = \alpha_1 f_1(x) + \alpha_2 f_2(x) + \cdots + \alpha_i f_i(x) + \cdots$$

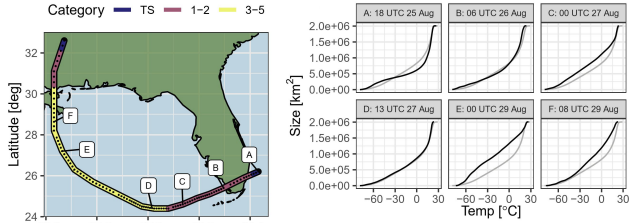
Current ORB functions only need 2 or 3 terms to explain ≥90% of variance

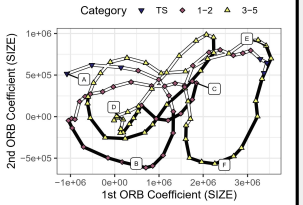
B Size functions

$$\mathscr{L}(c) = \{\mathbf{s} \mid T_b(\mathbf{s}) \le c\},\ \mathrm{Size}(c) = |\mathcal{L}(c)|$$

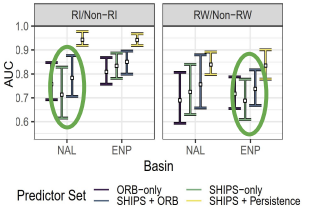


Tracking TC evolution over time with ORB coefficients





Nowcasting rapid intensity change with the logistic lasso



Summary of the ORB framework

- Extend traditional features to functions of thresholds/distance
- Compress ORB functions to ORB coefficients with PCA
- Analyze trajectories of ORB coefficients
- Relate ORB coefficients to intensity change

References

[1] McNeely, Trey, et al. "Unlocking GOES: A Statistical Framework for Quantifying the Evolution of Convective Structure in Tropical Cyclones." *Journal of Applied Meteorology and Climatology* 59.10 (2020): 1671-1689.

[2] McNeely, Trey, et al. "Structural Forecasting for Tropical Cyclone Intensity Prediction: Providing Insight with Deep Learning." *arXiv preprint arXiv:2010.05783* (2020).

[3] Ritchie, Elizabeth A., et al. "Tropical cyclone intensity estimation in the North Atlantic basin using an improved deviation angle variance technique." *Weather and forecasting* 27.5 (2012): 1264-1277.