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# Using Unsupervised Learning to Identify Severe Weather Regimes at Cape Canaveral

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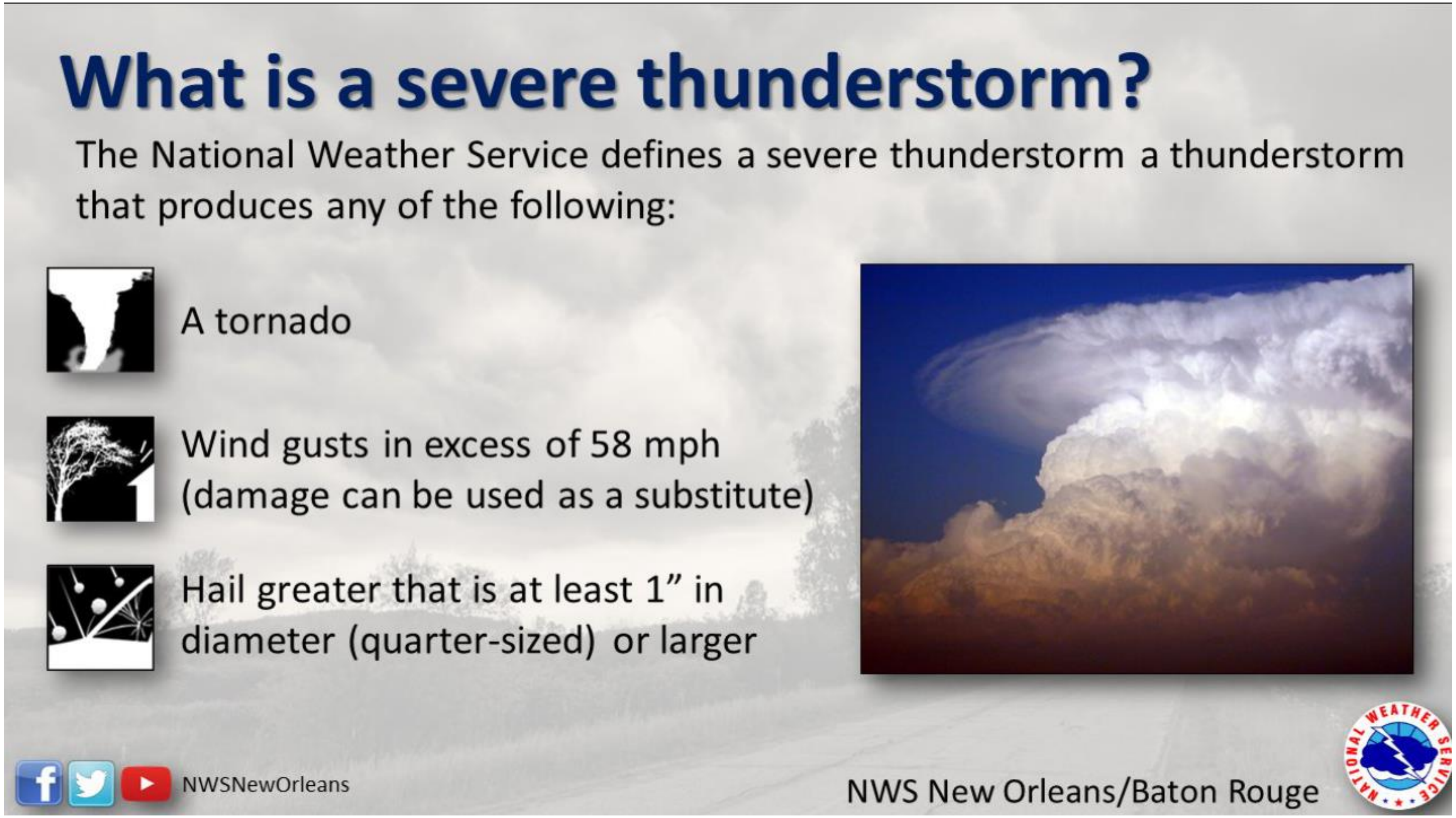
# Overview

- Background/Motivation
  - Mission Understanding
  - Data Acquisition
  - Data Understanding
- Methods
  - PCA
  - K-Means Clustering
- Analysis and Results
- Conclusion

# Motivation


If we accurately predict severe weather at KSC and CCSFS, we can prevent costly rocket hardware damage and launch delays

# A quick meteorological background




# Mission Understanding

- 45th Weather Squadron (45 WS) provides all operational weather support to KSC and CCSFS
- Some differences from NWS severe definition
  - Any size hail on KSC
  - ¾" on CCSFS
  - Wind speed verifiable up to 200/300ft (instead of 30ft)
- Launch Weather Officers issue severe forecasts for ground and launch operations; when rocket is exposed
- 45 WS has legacy forecast tools for lightning and severe weather


# My Approach

- Research Question: Using the 1500Z (1100am) weather balloon (sounding), can we identify different severe weather regimes?
- Features: all derived from the morning weather balloon launched daily from Cape Canaveral (KXMR)
  - Various parameters and indices that measure the ingredients needed for severe weather
- Only used days when severe weather occurred


# Data Acquisition

- Weather balloon data
  - Acquired via a request to the 14th Weather Squadron (climate unit)
  - Indices calculated from Python's MetPy library
- Pulled NWS severe reports from Iowa State University archive
- 45 WS severe warnings
  - Internal 45 WS database for all Warnings, Watches, and Advisories
- Wrote Python script to filter, and convert to a 0 or 1 for each day
- Merged datasets on date
- Only used days with severe weather (1 label)

# Data Understanding

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# Candidate Predictors

- 41 candidate predictors from 15Z sounding
- Measures of temperature, wind, wind shear, moisture, and instability at various altitudes


# Subsetting the Data

- Limited to just the Wet/Thunderstorm Season
  - May thru September
- Limited to just days when severe weather occurred within 30 miles of CCSFS/KSC

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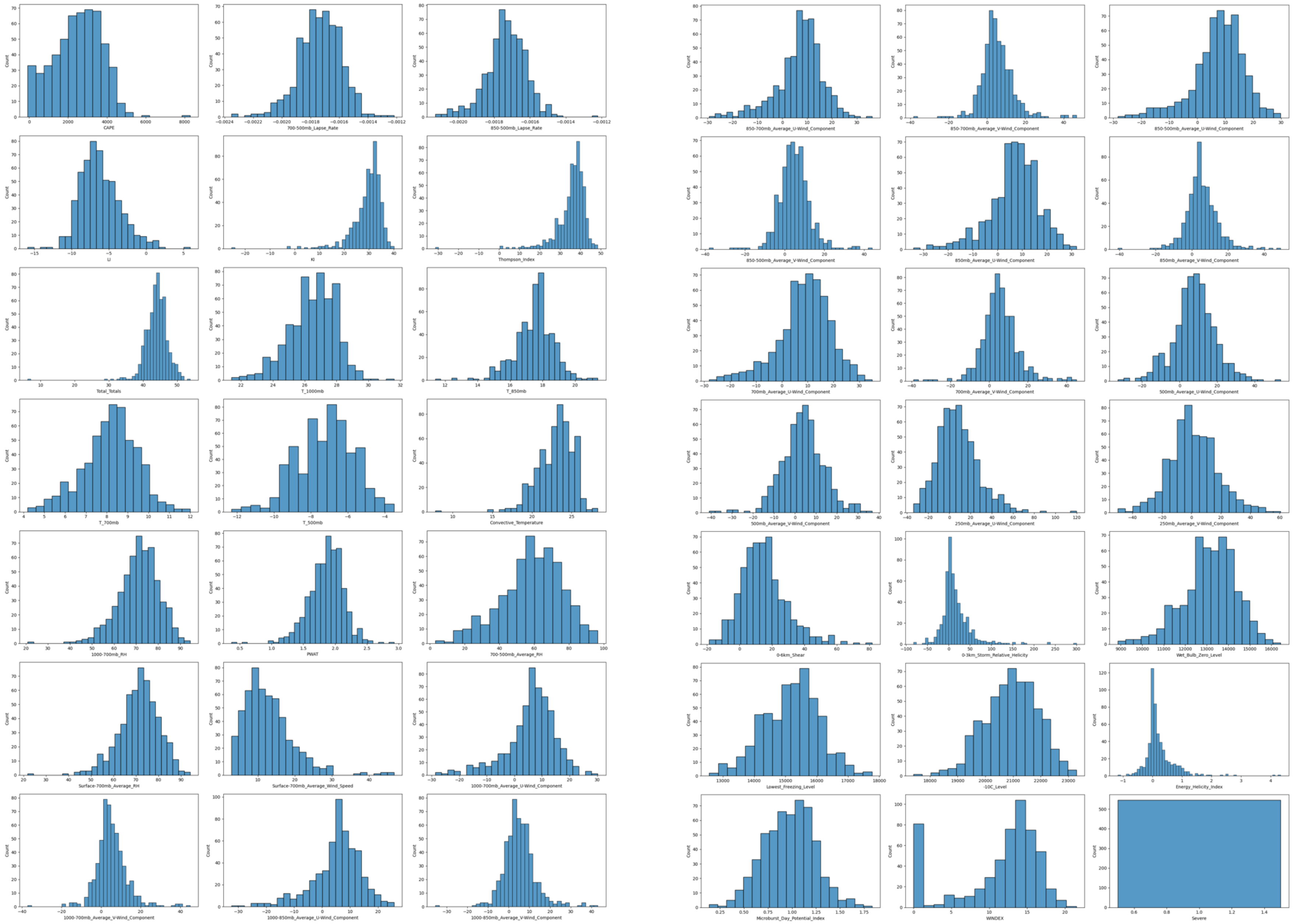


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# Methods


# Data Preparation

- Removed several candidate predictors
  - Reasons: too many null values, redundant, very highly correlated
- Removed obvious data errors

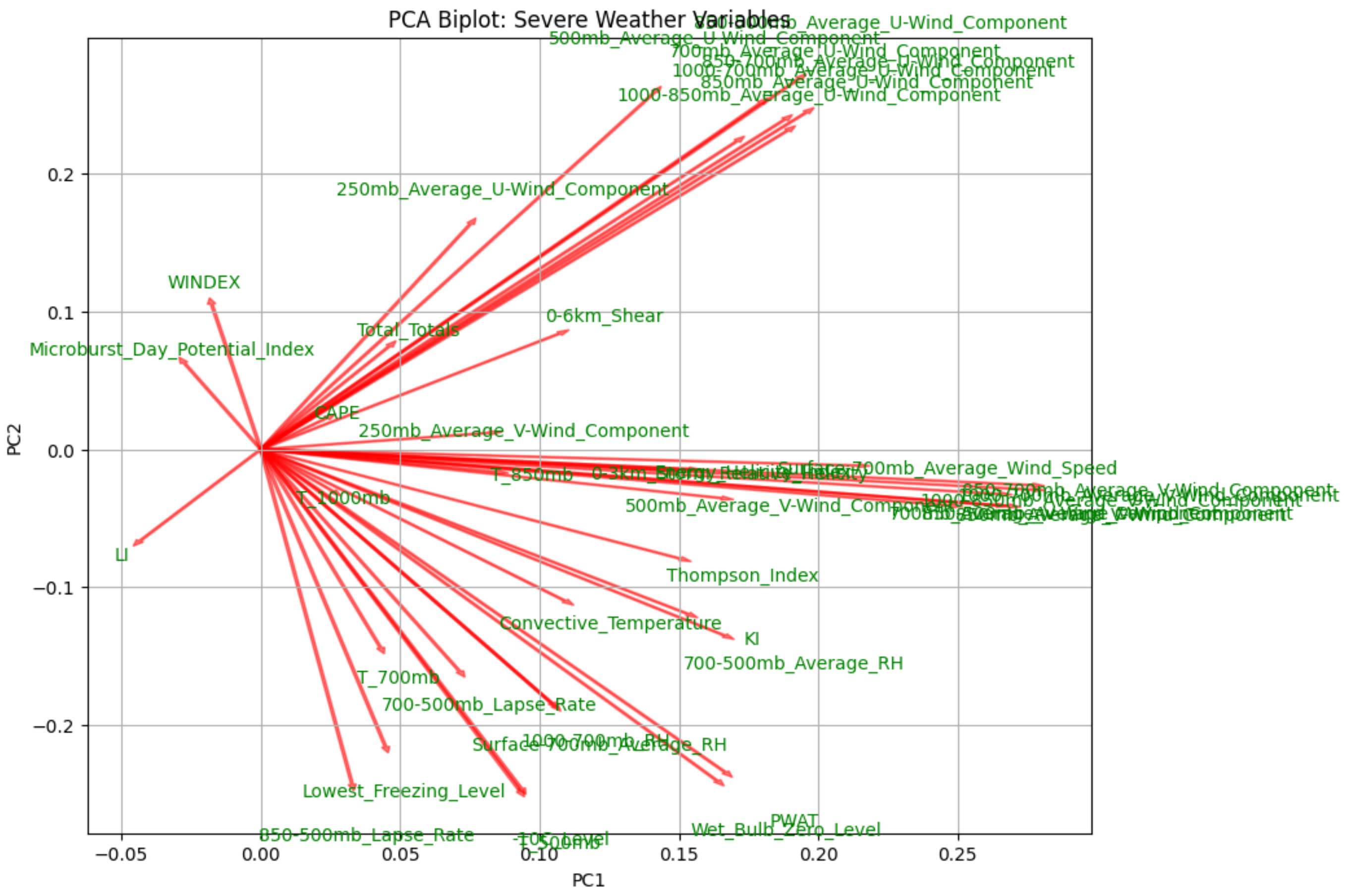

# Modeling Approach

- PCA
- K-Means Clustering


# Principal Component Analysis

- PCA reduced 40+ variables to two main components:
  - PC1: Instability and moisture (e.g., CAPE, PWAT, TT)
  - PC2: Kinematic support (e.g., shear, SRH, winds aloft)
- PCA enabled clearer visualization of regime structure

# PCA Biplot


PCA Biplot: Severe Weather Variables
500mb_Average_U-Wind_Component
700mb_Average_U-Wind_Component
850-700mb_Average_U-Wind_Component
1000-700mb_Average_U-Wind_Component
850mb_Average_U-Wind_Component
1000-850mb_Average_U-Wind_Component
250mb_Average_U-Wind_Component
WINDEX
Total_Totals
0-6km_Shear
Microburst_Day_Potential_Index
CAPE
250mb_Average_V-Wind_Component
Surface-700mb_Average_Wind_Speed
T_850mb
T_1000mb
500mb_Average_V-Wind_Component
LI
Thompson_Index
Convective_Temperature
KI
700-500mb_Average_RH
T_700mb
700-500mb_Lapse_Rate
Surface-700mb_Average_RH
Lowest_Freezing_Level
850-500mb_Lapse_Rate
PWAT
Wet_Bulb_Zero_Level
PC1
PC2
0.2
0.1
0.0
−0.1
−0.2
−0.05
0.00
0.05
0.10
0.15
0.20
0.25

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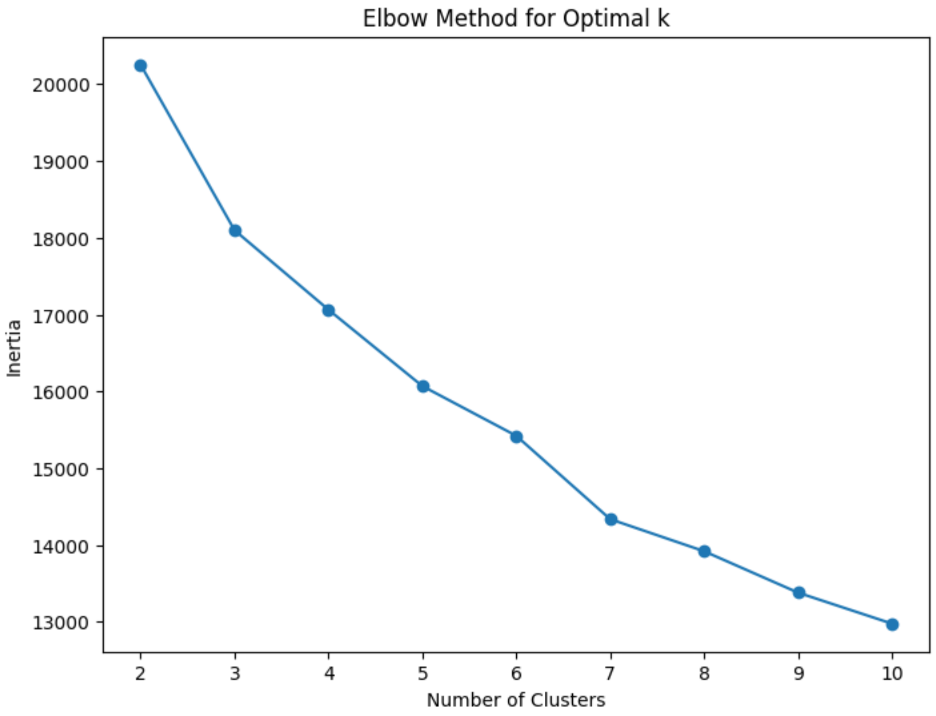
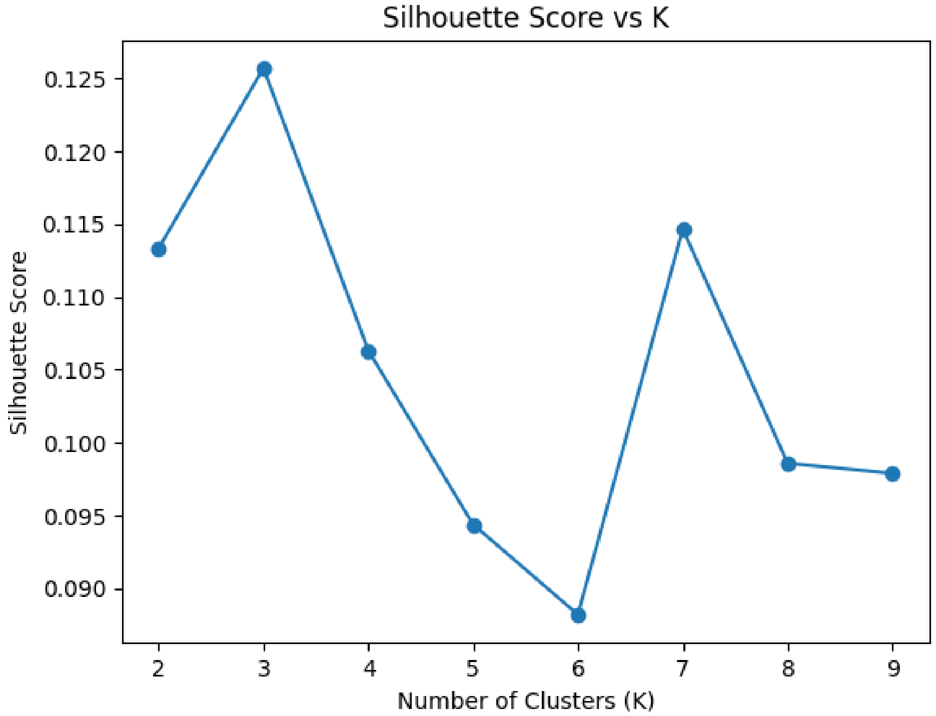
# K-Means Clustering



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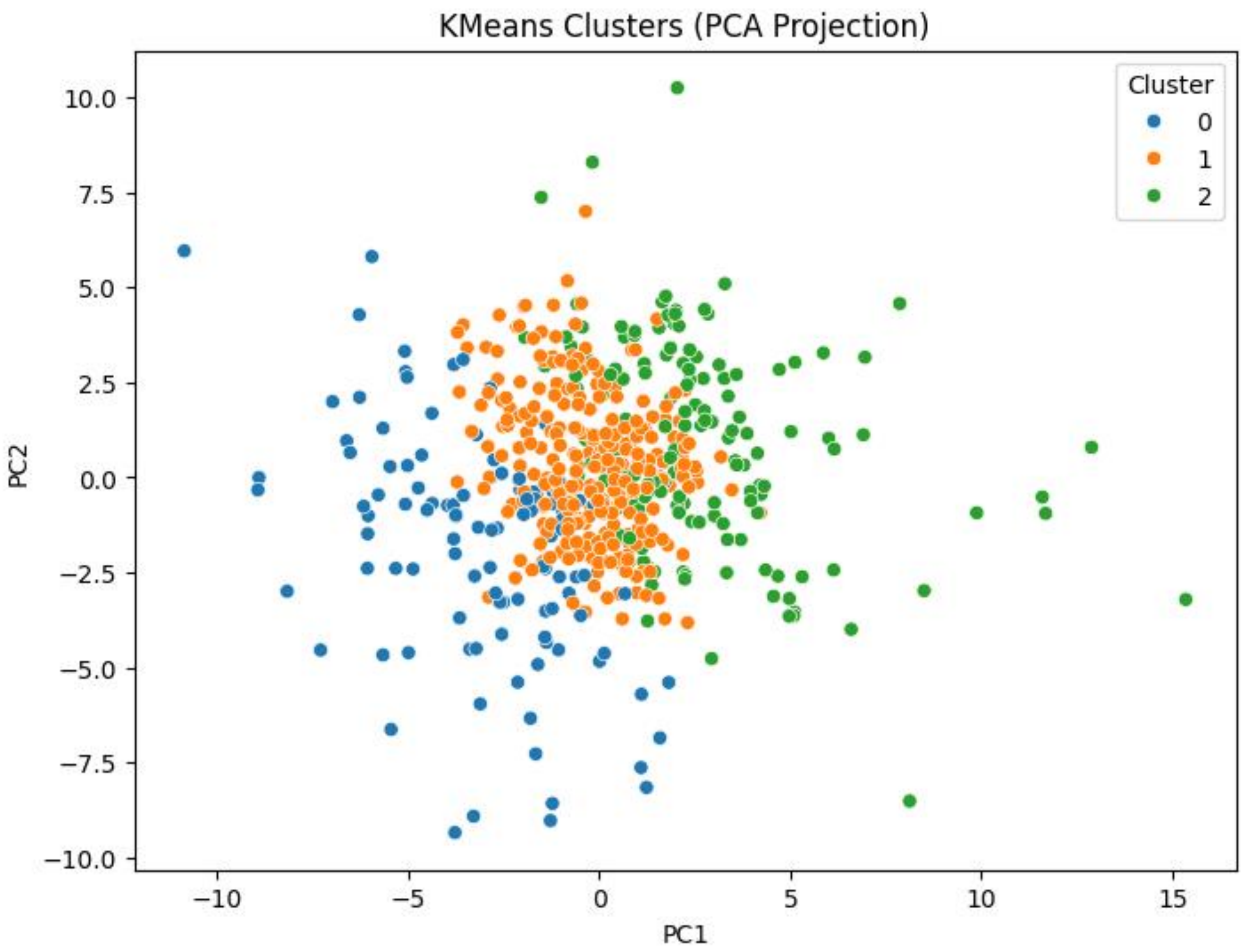


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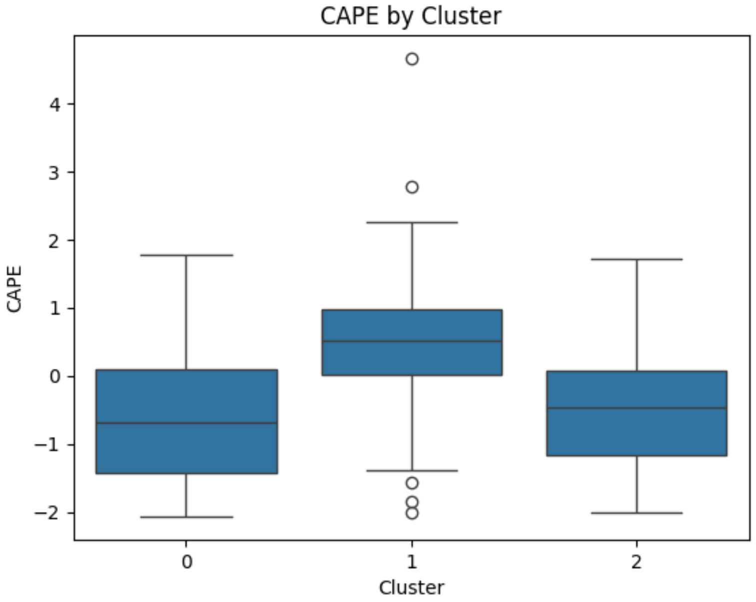
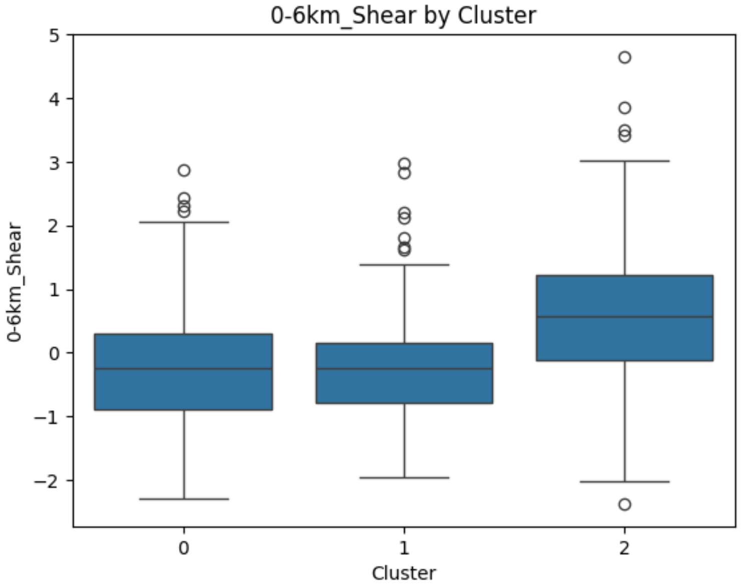
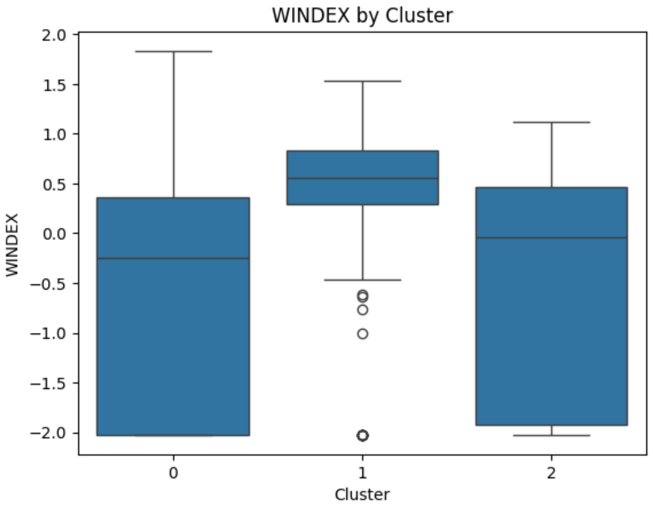
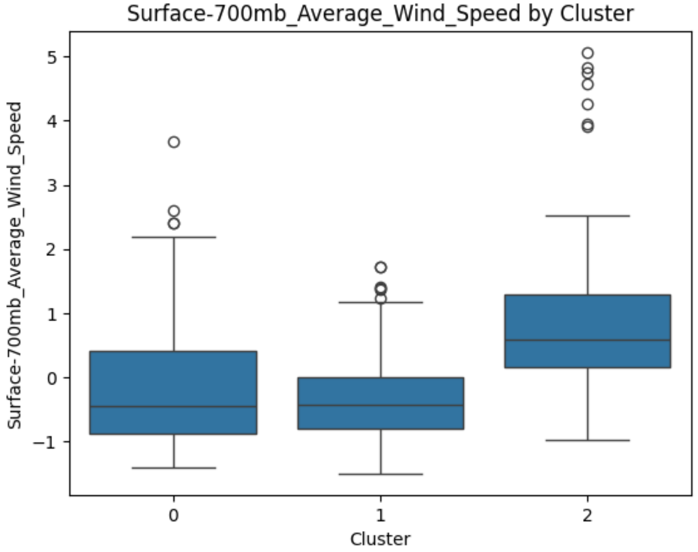
# Analysis/Results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# Model Evaluation

- Identified 3 primary regimes among severe events:
  - Cluster 0: Cool, weakly unstable environments
  - Cluster 1: Moist, warm-season pulse storm setups
  - Cluster 2: Dynamically forced, sheared environments

- Regimes suggest differing forecast concerns and storm modes.

# Conclusion


# Conclusion

- This work has potential to improve operations this summer
- Helps forecasters anticipate what *kind* of severe setup is present.
- Supports situational awareness potential severe weather days.
- Future work: Link regimes to individual threat types or add seasonal clustering.
- PCA + clustering provides a valuable lens on severe weather variability.