Atmospheric mesoscale dynamics over the North Atlantic: climatology based on Coherent Vortex Structures identification

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WHAT, WHERE, WHY?

What: Mesoscale Coherent Vortex Structures (CVSs)

- **spatial** and **temporal** persistent features of any continuous medium
- play a significant role in **dynamics** of atmosphere and ocean at **all scales**
- typically **ranging** from a few kilometers to hundreds of kilometers; **lasting** from hours to days
- large **variety** of types: tropical cyclones (TCs), tornadoes, polar mesocyclones, mesoscale convective systems (MCSs), katabatic processes, etc.

Where:

3D hindcast **North Atlantic Atmospheric Downscaling (NAAD)** for 1979-2018
(model: WRFv3, forcing: ERA-Interim, HiRes: 14 km, LoRes: 77 km)

Why:

absence of **universally** accepted mathematical **definition** for CVSs

many types of mesoscale processes have only **case studies**

lack of knowledge about their **climatic** characteristics and **impact**

Goal:

create a climate atlas of different types of mesoscale CVSs based on numerical data over the North Atlantic

DEVELOPMENT OF MESOSCALE ATLAS

Develop Robust Detection Algorithm

Create an algorithm for identifying and tracking CVSs

Rortex detection
DBSCAN separation
Automatic tracking

Provide Physically Justified Types

PCA reduction
KMeans clustering

Cluster CVSs based on thermodynamic characteristics

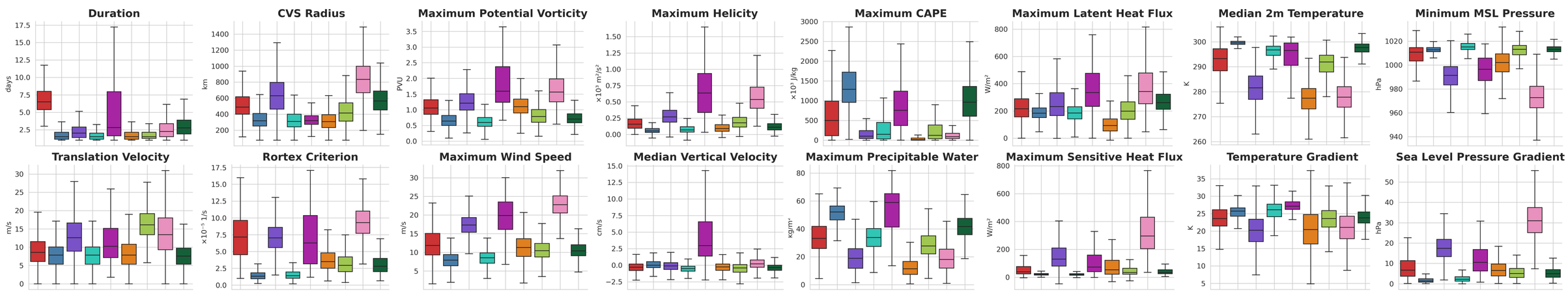
Obtain Climatology in North Atlantic

Get recurrence and intensity of CVSs in numerical data

Identify Long-Term Trends

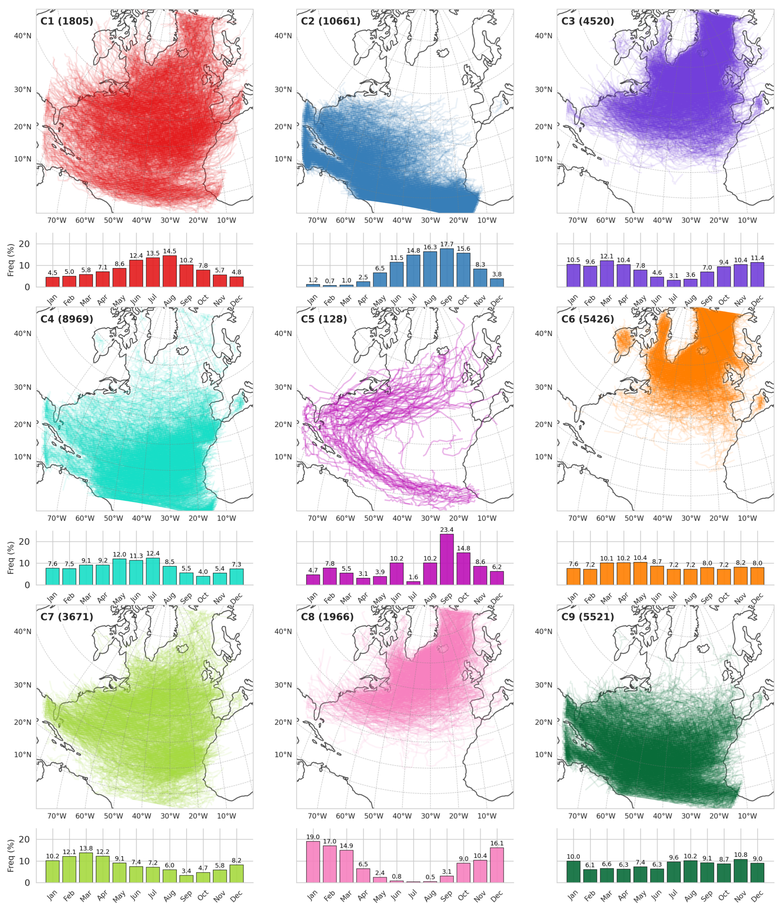
Find trends in CVSs characteristics over 1979-2018

CVSs FEATURES



SPATIOTEMPORAL RECURRENCE OF TYPES

Based on the set of 18 kinematic and physical CVSs features, mesoscale CVSs were clustered using KMeans (k = 9) with preliminary standardization and PCA reduction. Statistical distributions of key CVSs features are shown in the box plots above — each cluster is color-coded for direct comparison. Spatial trajectories and seasonal frequency of different types based on NAAD LoRes for 1979-2018 are presented below.

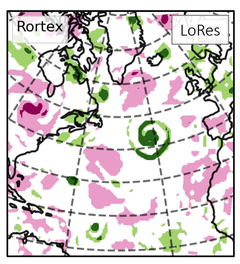


C2 (Blue): Dominates the tropical Atlantic with high summer occurrence. Characterized by elevated Convective Available Potential Energy (CAPE) and Precipitable Water, suggesting these are intense, moisture-rich **summertime convective systems**.

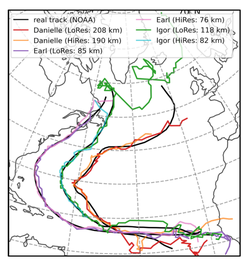
C5 (Purple): Tracks across the subtropical Atlantic, peaking in late summer/autumn. Features very high surface wind speeds and latent heat fluxes, strongly indicating this cluster represents **tropical cyclones**.

C8 (Pink): Dominates the midlatitude and subpolar Atlantic with high winter occurrence. Characterized by high intensity, large spatial scale, and strong sensible heat fluxes, suggesting these are **wintertime intense CVSs** (including polar lows).

TROPICAL CYCLONES ANALYSIS



Detected CVSs at 500 hPa

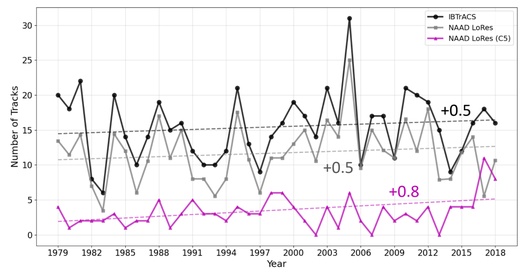


TCs tracks in summer 2010

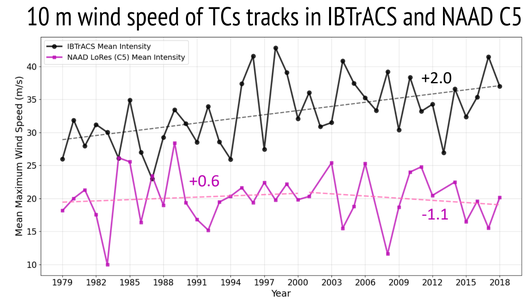
The method was tested for TCs Danielle, Earl and Igor in Aug-Sept 2010. The actual tracks of TCs (in black, IBTrACS database) is in good agreement with the automatic tracks (colored). The average distance between NOAA and NAAD track data does not exceed 210 km.

Black curves show values from the IBTrACS dataset; gray curves — matched tracks from the full NAAD LoRes trajectory dataset; purple curves — NAAD LoRes tracks in cluster C5 (strongest systems). Only 20 % of IBTrACS C5 tracks are captured by the NAAD LoRes C5 cluster, reflecting limitations in the tracking algorithm. This underrepresentation likely contributes to the lack of a significant intensity trend in modeled C5 systems and may explain the weak negative trend in maximum wind speed, as the model tends to dilute peak intensities by misclassifying or weakening the most extreme events.

Number of TCs tracks in IBTrACS and NAAD



10 m wind speed of TCs tracks in IBTrACS and NAAD C5



CONCLUSIONS

Robust algorithm for identifying and tracking mesoscale CVSs has been developed and tested over North Atlantic for the period 1979-2018. This toolkit made it possible to obtain the characteristics of each CVSs throughout its life cycle. This opened up the opportunity to conduct a preliminary clustering of different types of vortices based on their kinematic and thermodynamic characteristics. Based on the data obtained, long-term trends in the recurrence and intensity of mesoscale processes in the North Atlantic region are identified.

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