Exploring Trends in Tornado Clusters and Greenhouse Gas Concentrations

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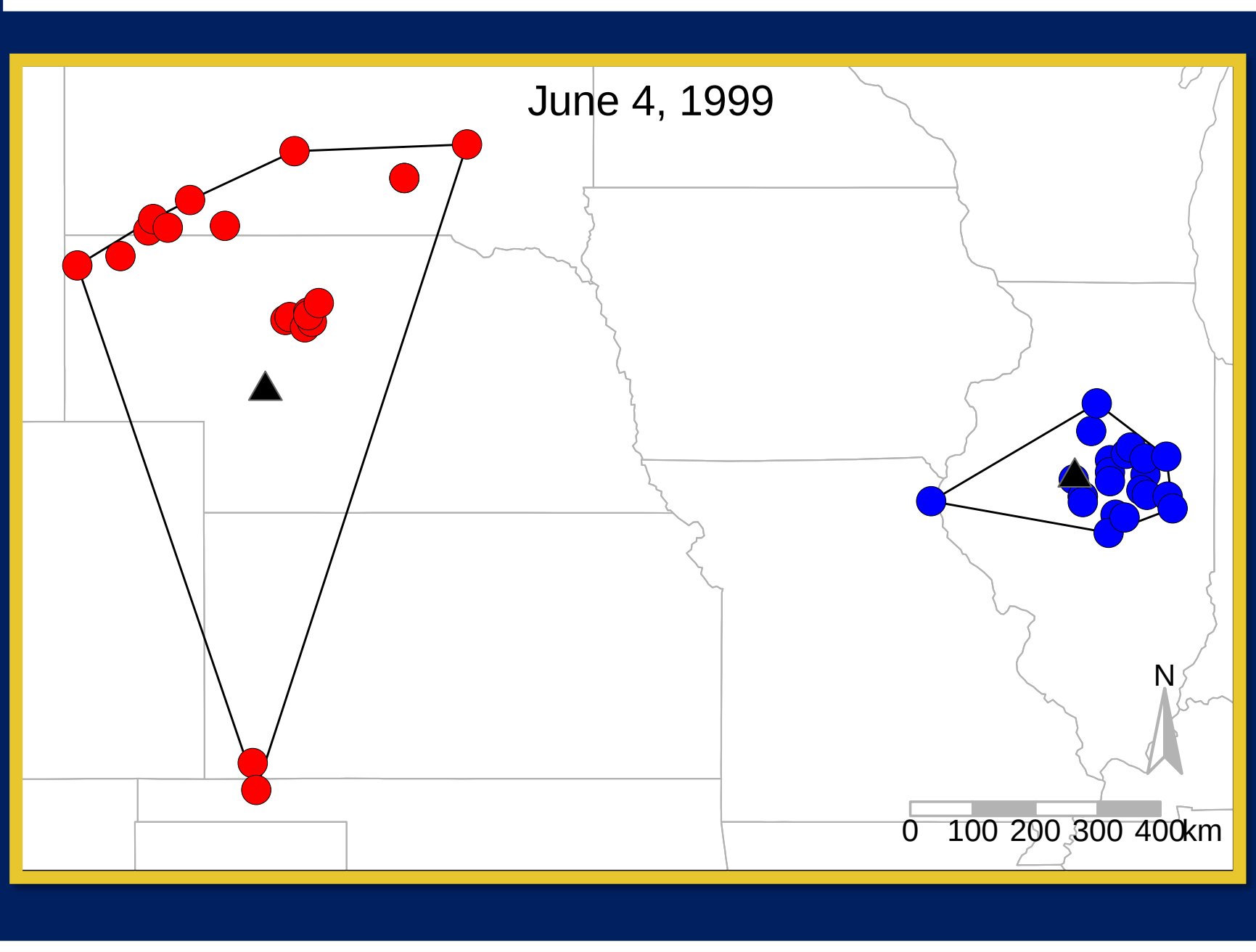
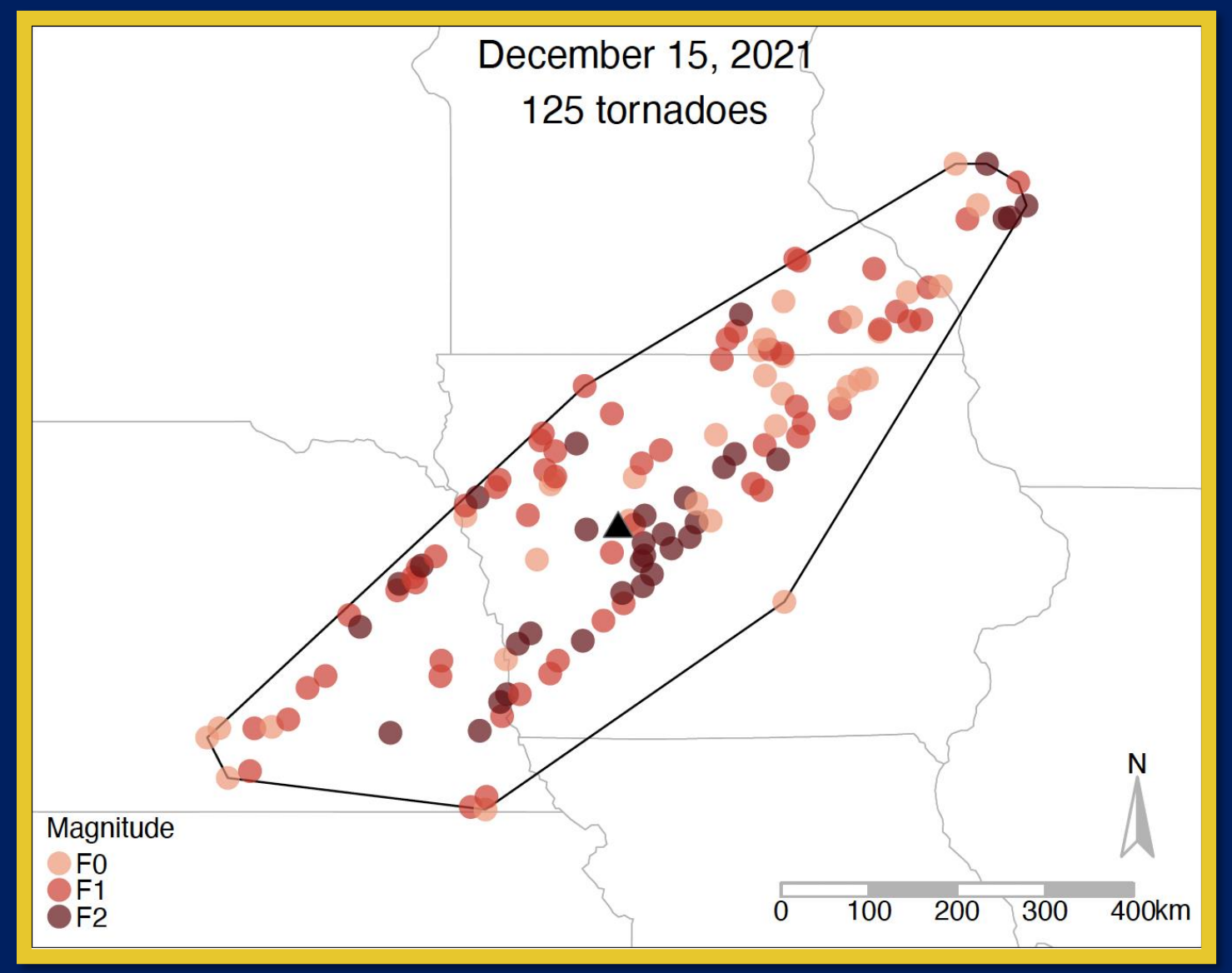
INTRODUCTION

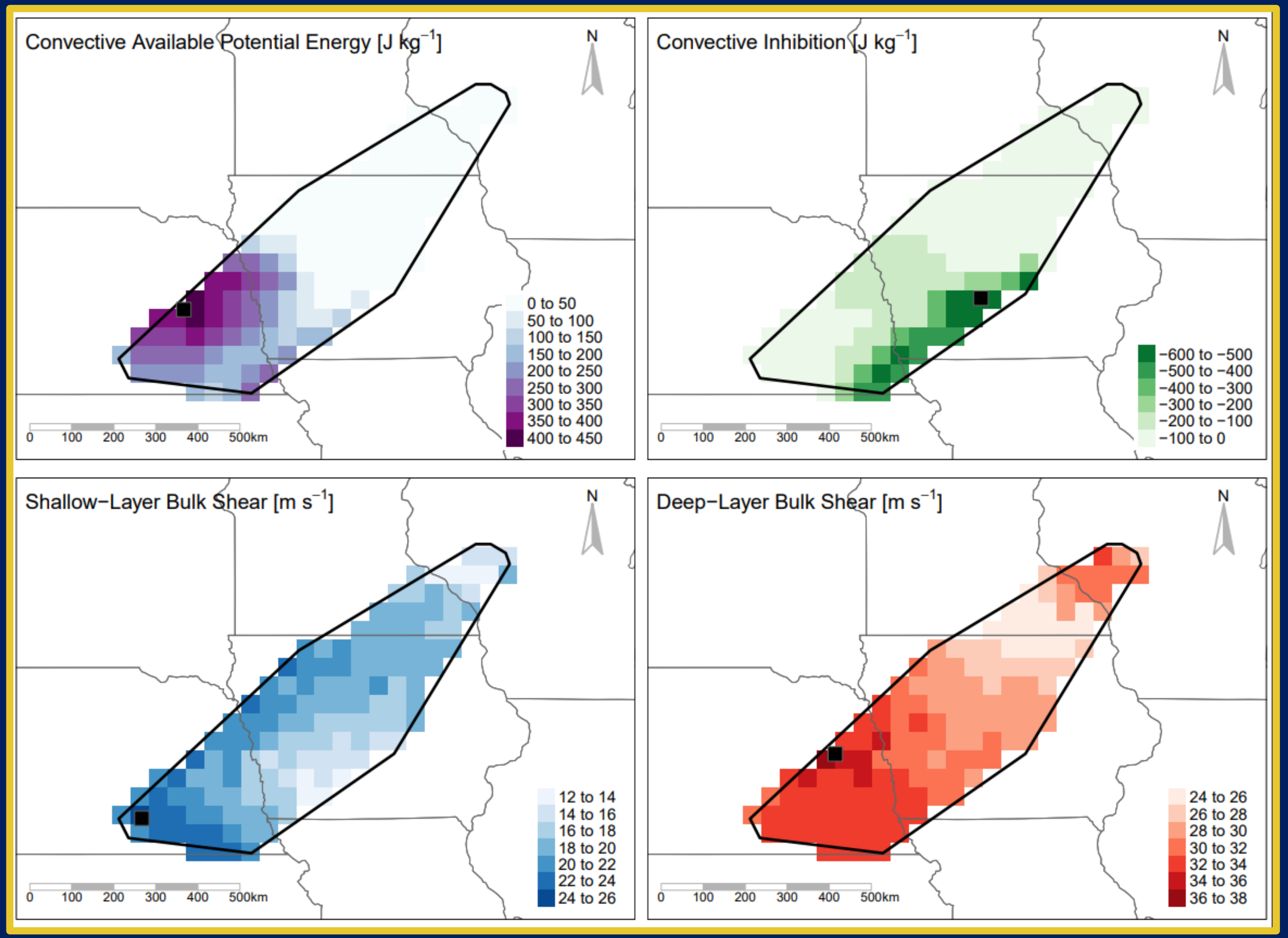
Tornado outbreaks continue to pose a high-risk to communities, especially communities in the central plains and lower Mississippi regions. Current research suggests an increases in tornadoes and outbreaks caused by tornadic-favorable environmental factors, such as, convective available potential energy (CAPE), convective inhibition (CIN), shallow and deep layer bulk wind shear (SLBS, DLBS) .[5] Greenhouse gas (GHG) concentrations are increasing and effect atmospheric composition through the greenhouse gas effect. Changes in atmospheric composition can change environmental factors by enhanced warming of the Earth and atmosphere.[1,2,3] More research is needed to explore how and if GHG emissions effect tornado outbreak climatology and tornadic-favorable environments. Tornado outbreak characteristics are defined as: total clusters, total tornadoes, total casualties, and convective environments. In this research, we will address the following question: How are tornado characteristics changing relative to changes in global GHG concentrations?

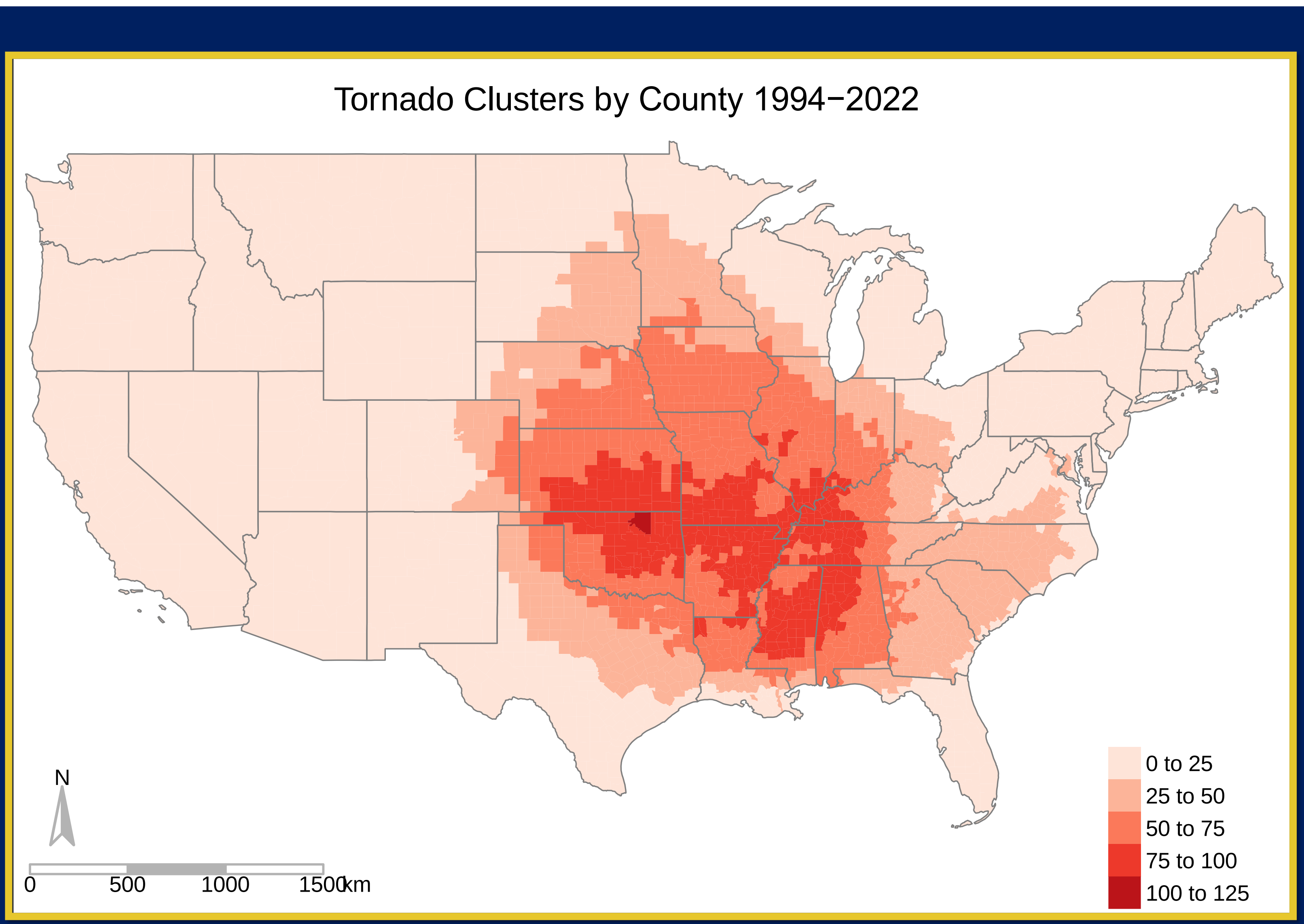




METHODS

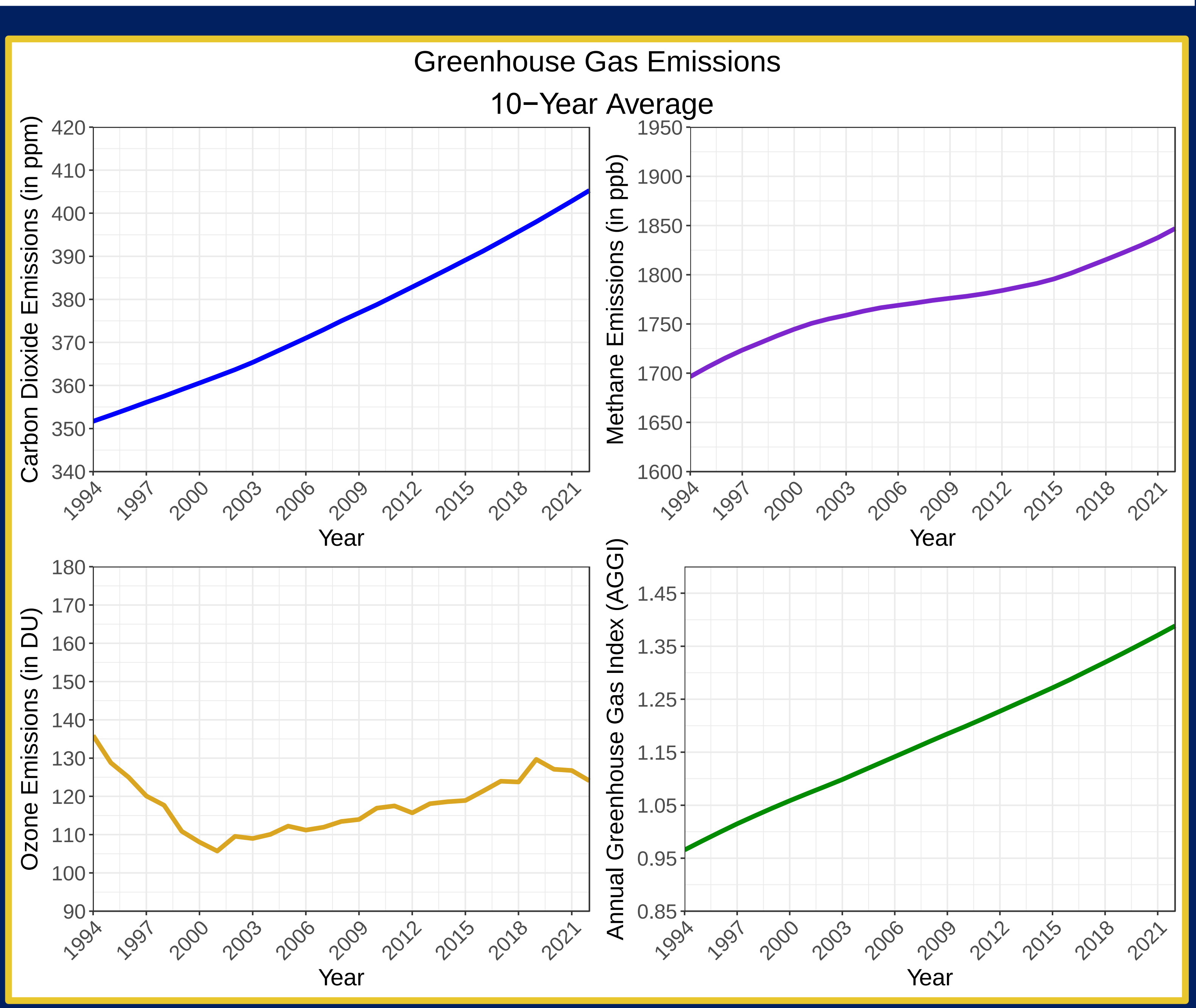
We collect tornado data from the Storm Prediction Center (SPC) for the years 1994 to 2022. Then, we use a hierarchical clustering algorithm developed in Schroder and Elsner 2019 to group the tornadoes based on their spatial and temporal relationships to each other.[6] This allows us to create tornado clusters by limiting clusters to ten or more tornadoes on a single convective day (24-hour period starting at 12 UTC). In total, there are 890 clusters with ten or more tornadoes in the contiguous United States. Next, we collect the environmental data from the National Center for Environmental Prediction's (NCEP) North American Regional Reanalysis (NARR). We fit the closest 3-hour NARR time prior to the first tornado in each cluster to collect the maximum value of convective available potential energy (CAPE), deep-layer bulk shear (DLBS), and shallow-layer bulk shear (SLBS) and the minimum value of convective inhibition (CIN) to represent each cluster. Greenhouse Gas (GHG) concentration data for Carbon Dioxide (CO_2), Methane (CH_4), Ozone (O_3), and the Annual Greenhouse Gas Index (AGGI) were collected from Global Monitoring Laboratory (GML). We compute the 5-year and 10-year average values for each outbreak. We test the significance of trends in cluster characteristics (total clusters, total tornadoes, total casualties), environmental variables, and GHG concentrations with respect to time. Additionally, correlation and t-tests are employed to test significant relationships between GHG concentrations, cluster characteristics, and environmental variables.

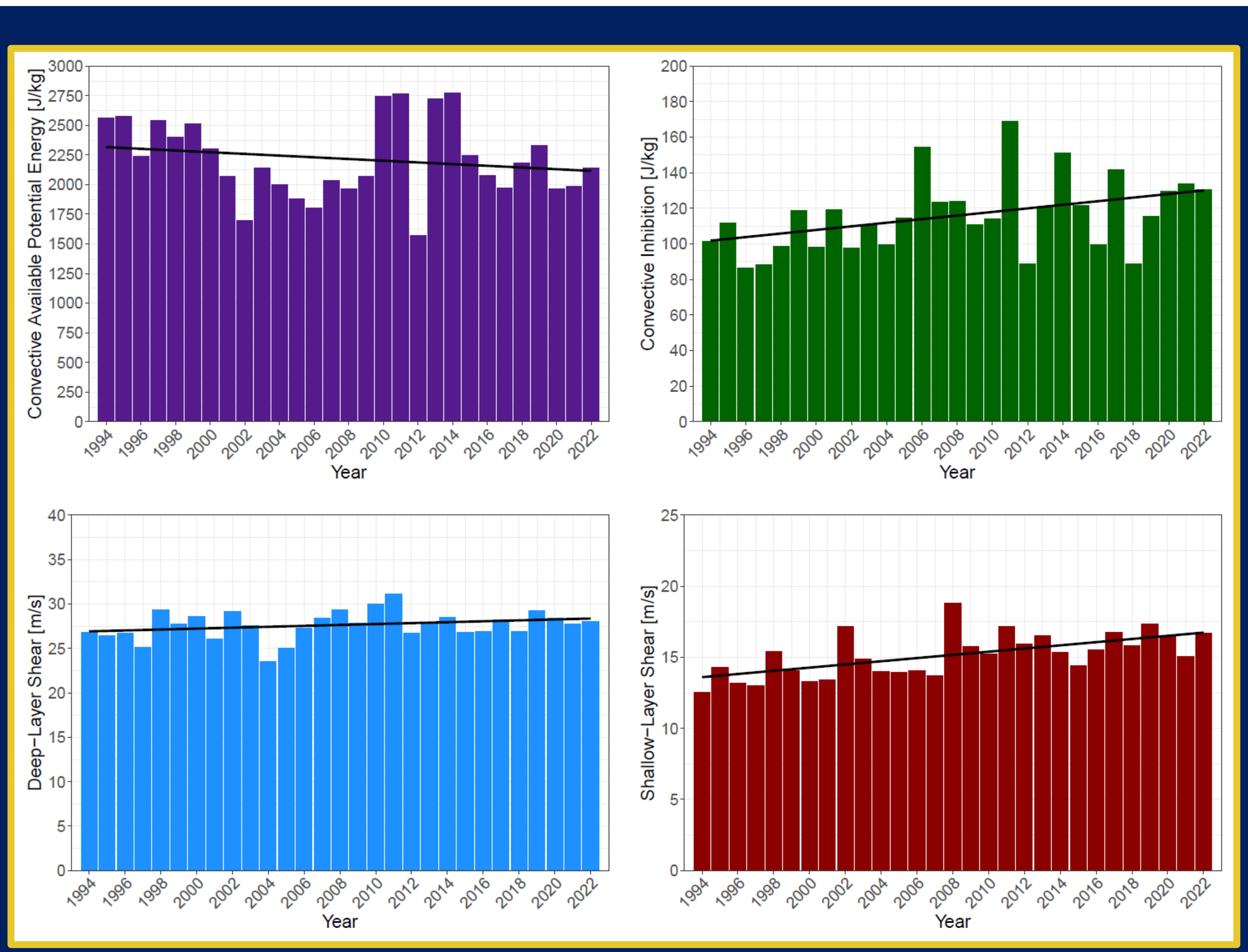




RESULTS

The greatest density of clusters in the data occurred in Osage County, Oklahoma with 107 clusters impacting the area between 1994 and 2022. Overall, the total number of clusters and total number of tornadoes is increasing overtime. However, this trend is not significant with a p-value > 0.7. The total number of casualties appears to decrease overtime. However, this trend is not significant with a p-value > 0.7. As for the convective environments, CIN (p-value: 0.01), DLBS (p-value: 0.05), and SLBS (p-value: < 0.001) are increasing at a significant rate annually. The GHG concentrations, excluding O_3, are also significantly increasing over time. It is important to note that CO_2, CH_4, and AGGI are positively correlated with values > 0.98. The relationship between cluster characteristics and GHG concentrations does not yield significant results. However, there is a significant relationship between environmental variables and GHG concentrations. SLBS, CO_2, CH_4, and AGGI are significantly related with a p-value less than 0.001. CIN, CO_2, CH_4, and AGGI are significantly related with a p-value of 0.01. CAPE and DLBS are not significantly impacted by GHG emissions (p-value > 0.07). Correlation indicates that there is no collinearity issues between the environmental variables and GHG concentrations although they are significantly related. Future research will quantify the relationship between GHG concentrations and convective environments conducive for tornado activity in the United States.





Environmental Variable	Carbon Dioxide	Methane	Ozone	AGGI
Convective Available Potential Energy	0.24	0.07	0.07	0.20
Convective Inhibition	**0.01**	**0.01**	0.87	**0.01**
Deep-Layer Bulk Shear	0.06	0.09	0.35	0.06
Shallow-Layer Bulk Shear	**< 0.001**	**< 0.001**	0.36	**< 0.001**

CONCLUSIONS

Tornado outbreaks remain to be significant risk to communities and the weather community. We use 890 tornado clusters to determine the relationship between cluster characteristics, convective environments, and GHG concentrations. CO_2, CH_4, AGGI, CIN, DLBS, and SLBS are significantly increasing per annum. Although GHG concentrations are on the rise, there is no significant relationship with total clusters, total tornadoes, or total casualties annually. GHG concentrations were found to have a significant relationship with convective environment, such as SLBS and CIN. More research is needed to understand the direct and physical impacts of GHGs on tornado outbreak environments as these concentrations continue to increase in the future.

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