

# TopoFlow: A Novel Topology-Based Poincaré-Hopf Detection System for Atmospheric Stagnation Points, CH<sub>4</sub> Hotspot Identification & Cross-Planetary Analysis

<sup>1</sup>SHANZA SAMI

<sup>1</sup>West Senior High School, 2901 Melrose Ave. 52246

Email: [shanza-sami@uiowa.edu](mailto:shanza-sami@uiowa.edu)

---

## ABSTRACT

Atmospheric transport drives the dispersion and accumulation of trace gases, yet the topological constraints imposed on global wind fields remain underutilized in environmental analysis. The Hairy Ball Theorem guarantees that any continuous tangential flow on a sphere must contain zero-velocity points, while the Poincaré-Hopf theorem constrains the summed index of these stagnation points to the Euler characteristic of the sphere. This study develops a topology-informed diagnostic framework to detect, classify, and map atmospheric stagnation structures and evaluate their role in methane (CH<sub>4</sub>) accumulation. Using ERA5 10 m u- and v-wind fields (2010-2024), a sub-grid bilinear root-finding and Jacobian classification framework was developed to detect and categorize instantaneous surface stagnation points. Time-resolved index closure tests yielded a mean summed index of  $\pm 2$ , which is consistent with theoretical predictions. Persistence mapping revealed recurrent saddle-dominated stagnation corridors in subtropical regions and during midlatitude blocking events. When located alongside Sentinel-5P methane retrievals, persistent stagnation zones exhibited statistically significant CH<sub>4</sub> enhancements ( $p < 0.01$ ) and positive lag correlations at 0-3 day lag, which indicates suppressed advective dispersion. Sensitivity analyses further demonstrate resolution-dependent deviations in index conservation within reanalysis products. Because the methodology depends only on manifold topology, it generalizes naturally to other planetary atmospheres. These results establish topological flow analysis as a novel mapping tool for methane hotspot identification and atmospheric transport modeling.