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Hyperbolic Covariant Coherent Structures in Two Dimensional Flows

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A new method to describe hyperbolic patterns in two-dimensional flows is proposed. The method is based on the Covariant Lyapunov Vectors (CLVs), which have the properties of being covariant with the dynamics, and thus, being mapped by the tangent linear operator into another CLVs basis, they are norm independent, invariant under time reversal and cannot be orthonormal. CLVs can thus give more detailed information about the expansion and contraction directions of the flow than the Lyapunov vector bases, which are instead always orthogonal. We suggest a definition of Hyperbolic Covariant Coherent Structures (HCCSs), which can be defined on the scalar field representing the angle between the CLVs. HCCSs can be defined for every time instant and could be useful to understand the long-term behavior of particle tracers. We consider three examples: a simple autonomous Hamiltonian system, as well as the non-autonomous "double gyre" and Bickley jet, to see how well the angle is able to describe particular patterns and barriers. We compare the results from the HCCSs with other coherent patterns defined on finite time by the Finite Time Lyapunov Exponents (FTLEs), to see how the behaviors of these structures change asymptotically.