§20. Spatiotemporal Chaos, Stochasticity and Coherent Structures in Toroidal Magnetic Configurations

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A more complete insight into the turbulence and transport, zonal flow dynamics and the nature of stochasticity in toroidal systems (helical and tokamak) is pursued by means of the analysis of nonlinear gyrokinetic Vlasov simulation (GKV) data, for the tokamak and the standard and the inward shifted helical configurations [1-3] from the aspect of nonlinear dynamic systems theory. In both the tokamak and the helical systems stochasticity arises from the spatiotemporal chaos (STC). Reduction of transport in the inward shifted configuration with respect to the standard one is interpreted as a consequence of STC suppression and the relevance of Kolmogorov-Sinai entropy and Lyapunov exponents (spectrum) in determination of transport properties is also discussed [4]. Analysis of coherent vortex structures has been performed using Proper Orthogonal Decomposition (POD) and Independent Component Analysis (ICA). Well adapted for studies of spatiotemporal dynamics, either deterministic or stochastic, POD is already established and used with much success in both, fluids and plasmas analyses. This method is also known under different names in diverse scientific fields, e.g., the Singular Value Decomposition (SVD) in linear algebra, Karhunen-Loewe decomposition in statistics and bi-orthogonal decomposition in physics. One of the notable advantages of the POD is that the method is data dependent so that collective modes (base) are not given in advance, contrary to a case when the analyst subjectively has to choose an appropriate basis for a given case (e.g. wavelets).

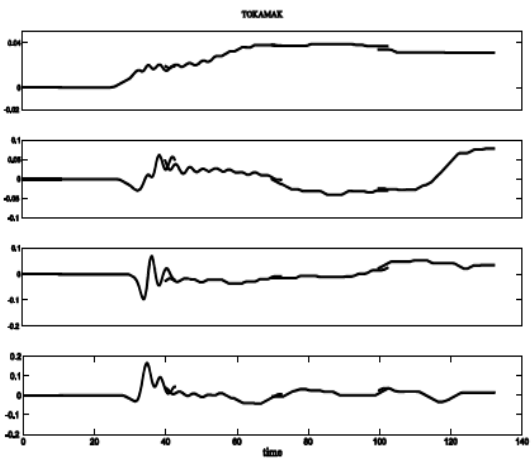

Fig.1. First four temporal eigenfunctions of the proper orthogonal decomposition (POD) of the zonal flow potential for the tokamak configuration [2].

When applied to spatiotemporal data the POD usually extracts spatially delocalized modes, and in the system which has a translational symmetry, that implies statistical homogeneity, the basis consists of Fourier functions, so that the field is given as linear combination of plane waves. In many cases this may present a disadvantage so alternative types of decompositions may be more desirable. Moreover, in the POD the coherent structures are inferred from all flow realizations, and such that ones with the highest energy are chosen to optimally represent the field.

As an illustration of the POD analysis, in Fig. 1, temporal eigenfunctions of the zonal flows [2], for the tokamak configuration are shown with noticeable GAM oscillations. As mentioned, it turns out that while the POD method being appropriate and efficient into decomposing field variables into delocalized modes; as well as, other similar methods, it normally fails to take into account local coherent field structures. Therefore, in order to achieve such a task, we apply ICA, a very recently developed method in statistical signal analysis which has a goal of decomposing mixed multivariate signals into a set of maximally statistically independent components [5]. This is of particular relevance in the interaction between zonal flows and turbulence, as we would be interested to extract the structure and the space-time advancement of individual modes whose interplay forms full spatiotemporal dynamics. We believe that ICA method will prove of great importance in extraction of coherent structures, such as vortices and solitary structures (solitons) from spatiotemporal dynamics of chaotic and turbulent systems, such as fusion plasmas.

Further, we have shown that ICA is superior in extraction of spatially or temporally localized solitary structures, while a combination of both decomposition methods may offer valuable information on the spatiotemporal dynamics of zonal flows. Such as e.g., that interaction of only few of the most energetic coherent vortices contributes and controls the spatiotemporal dynamic and pattern formation of the zonal flows. Finally, we discuss how above methods can be used in future for comparison and validation of simulation data against the experimentally measured results.

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1. H. Sugama and T.-H. Watanabe, Phys. of Plasmas 13 (2006) 012501.
2. S. Ferrando-Margalet, H. Sugama, and T.-H. Watanabe, Phys. of Plasmas, 14 (2007) 122505.
3. T. -H. Watanabe, H. Sugama and S. Ferrando-Margalet, Phys. Rev. Lett. 100 (2008) 195002.
4. M. R. Rajković, T.-H. Watanabe and M.M. Škorić, Phys. of Plasmas 16 (2009) 092306.
5. M. R. Rajković, T.-H. Watanabe and M.M. Škorić, talk at EPS Workshop on Electric Fields, Turbulence and Self-Organization in Magnetized Plasmas, Strasbourg (2011)