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# Effect of Oscillation Structures on Inertial-Range Intermittence and Topology in Turbulent Field

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**Abstract.** Using the incompressible isotropic turbulent fields obtained from direct numerical simulation and large-eddy simulation, we studied the statistics of oscillation structures based on local zero-crossings and their relation with inertial-range intermittency for transverse velocity and passive scalar. Our results show that for both the velocity and passive scalar, the local oscillation structures are statistically scale-invariant at high Reynolds number, and the inertial-range intermittency of the overall flow region is determined by the most intermittent structures characterized by one local zero-crossing. Local flow patterns conditioned on the oscillation structures are characterized by the joint probability density function of the invariants of the filtered velocity gradient tensor at inertial range. We demonstrate that the most intermittent regions for longitudinal velocity tend to lay at the saddle area, while those for the transverse velocity tend to locate at the vortex-dominated area. The connection between the ramp-cliff structures in passive scalar field and the corresponding saddle regions in the velocity field is also verified by the approach of oscillation structure classification.

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## 1 Introduction

Inertial-range intermittency is a well-known feature in turbulent flows quantified by the anomalous scaling of structure functions $S_p(r)$. In isotropic velocity field, $S_p(r)$ can be either the longitudinal structure function $S_p(r)=\langle|\delta_r u|^p\rangle$, or the transverse structure function $S_p^T(r)=\langle|\delta_r v|^p\rangle$. Here $\langle\cdots\rangle$ denotes the ensemble average, $\delta_r u=u(x+r/2)-u(x-r/2)$

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and $\delta_r v = v(x+r/2) - v(x-r/2)$, where $u$ and $v$ are the velocity components in the same and normal directions to the separation $r$, respectively. Kolmogorov's similarity theory [1,2] predicted the simple scaling behavior that $S_p(r) \sim r^{\zeta_p}$ and $S_p^T(r) \sim r^{\zeta_p^T}$, with both $\zeta_p$ and $\zeta_p^T$ equal to $p/3$. Experimental measurements and numerical simulations showed that the scaling exponents $\zeta_p$ and $\zeta_p^T$ depart from $p/3$ when $p \neq 3$ [3–10]. The intermittent behavior has also been observed in the passive scalar field $\theta$ [5,11,12], that the structure function $S_p^\theta(r)$ has a scaling $\xi_p$ departing from $p/3$ as predicted by the KOC theory of Obukhov [13] and Corrsin [14], where $S_p^\theta(r) = \langle|\delta_r \theta|^p\rangle$ and $\delta_r \theta = \theta(x+r/2) - \theta(x-r/2)$.

Many models have been proposed to describe the anomalous scaling of structure functions of velocity [3, 15–19] and passive scalar [20–24]. These models present more and more accurate depiction of the scaling exponents, however the essence of intermittence remains to be an open issue, and the corresponding debates are briefly summarized as follows:

(1) For the longitudinal velocity structure function, it was predicted that the intense vortex structures are responsible for the inertial-range intermittency [18, 25, 26], while Sain et al. [27] argued that the existence of vortex filaments is not crucial for the anomalous scaling.

(2) For the transverse velocity structure function, plenty of works have been devoted to clarify whether $\zeta_p^T$ should be equal to $\zeta_p$. Biferale and Procaccia [28] stated that $\zeta_p^T$ should be equal to $\zeta_p$ theoretically, and this relation appears to be supported by some experimental measurements [29, 30]. On the other hand, many experimental results [6,31,32] and numerical simulations [4,33] suggest that these two scalings are different. It is argued that anisotropy [34,35] and finite Reynolds number effects [34,36] have large contribution to the difference between the $\zeta_p^T$ and $\zeta_p$, while the discrepancy can still be observed in the experimental measurement at Reynolds number of about $10^4$ [6] and DNS fields where the isotropy can be welly maintained [7–10]. Boratav and Pelz [33] inferred that the difference of $\zeta_p^T$ and $\zeta_p$ is due to an imbalance contribution to intermittency of the enstrophy-dominated and the strain-dominated regions. Chen et al. [19] studied the relation between enstrophy and $S_p^T(r)$, and proposed the refined similarity hypothesis for transverse velocity increments, which is verified by their DNS data and further supported by the experimental measurement of Zhou et al. [37].

(3) For the passive scalar field, it was shown that when a mean gradient of passive scalar was imposed, the ramp-cliff structures would cause the isotropy to be violated at very small scales [11,12,38,39]. Warhaft conjectured that the departure from local isotropy at the small scales and the internal intermittency are intimately related [11]. However, to the best of our knowledge, no work has provided a clear description about the connection between the flow structures and the inertial-range intermittency of passive scalar.

In the companion paper [40], the effect of the geometric properties on the anomalous scaling of longitudinal velocity structure function was studied, using the newly developed oscillation structure (OS) classification based on local zero-crossings. It was found