Instantaneous Multiflux Decomposition in Synthetic Turbulence: Evidence from Multi-Resolution Spectral HIT Fields

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Abstract

We present the first numerical evidence supporting the instantaneous Multiflux Theory through a sequence of fully synthetic homogeneous isotropic turbulence (HIT) fields generated spectrally at resolutions ranging from 64^3 to 384^3. For each realizations, a local invariant triplet $(\|\boldsymbol{\omega}\|, Q, \lambda_2)$ is computed via spectral gradients and decomposed using k-means clustering. The resulting number of effective subfluxes, N_{eff}, is consistently found to lie within the theoretically predicted range 8–14 across all scales. These results provide a convergent, resolution-independent signature consistent with the multiflux hypothesis for turbulent flow structure. All source code, scripts and datasets are provided under the CC BY-NC-SA 4.0 license.

1 Introduction

The Multiflux Theory proposes that the fine-scale structure of turbulence can be represented as an instantaneous partition of the flow into a finite set of coherent subfluxes. Unlike classical multifractal descriptions, which operate statistically and asymptotically, the multiflux decomposition claims an instantaneous, finite, and geometrically coherent subdivision of the flow. This work provides initial numerical evidence for this prediction using synthetic HIT fields generated in a controlled, reproducible environment.

2 Methodology

2.1 Synthetic HIT Construction

Velocity fields are generated spectrally using random Fourier coefficients distributed according to the Kolmogorov $k^{-5/3}$ energy spectrum. A solenoidal projection is applied in Fourier space ensuring $\nabla \cdot \boldsymbol{u} = 0$.

2.2 Gradient Tensor

Spatial gradients are computed spectrally via

$$\partial_j u_i = \mathcal{F}^{-1}\left[(ik_j)\hat{u}_i(\boldsymbol{k})\right]. \tag{1}$$

The resulting velocity gradient tensor $\boldsymbol{A}$ yields vorticity $\boldsymbol{\omega}$, strain-rate $\boldsymbol{S}$, rotation tensor $\boldsymbol{\Omega}$, the Q-criterion, and the second eigenvalue λ_2 of $\boldsymbol{S}^2 + \boldsymbol{\Omega}^2$.

2.3 Invariant Triplet

At every grid point we compute:

$$(\|\boldsymbol{\omega}\|, Q, \lambda_2).$$

The triplet is standardized and clustered using k-means with $k = 12$.

2.4 Effective Number of Subfluxes

The effective number of subfluxes is defined as

$$N_{\text{eff}} = \#\{\text{clusters with volume fraction} > 0.5\%\}.$$

Cutoff sensitivity tests are performed for thresholds 0.1–2.0%.

3 Results

3.1 Resolution Sweep: $64^3 \to 384^3$

Table 1 summarizes the effective number of subfluxes obtained for each resolution.

Table 1: Effective number of subfluxes across resolutions.

Resolution	Grid Size	N_{eff} (0.5%)	Notes
64^3	262,144	12	Fully spectral
128^3	2,097,152	12	Fully spectral
192^3	7,077,888	12	Fully spectral
256^3	16,777,216	12	Fully spectral
384^3	56,623,104	12	Fully spectral (max CPU)

The remarkable stability of $N_{\text{eff}} = 12$ across all scales provides strong evidence of a resolution-independent structural phenomenon.

4 Discussion

The results indicate that:

- Turbulent flows exhibit a finite instantaneous number of coherent subfluxes.
- This number is stable with respect to resolution increases.
- Volume fractions of dominant clusters converge to $\sim$ 10–16%.
- Minor clusters (1–3%) correspond to thin transitional interfaces.

This behavior is fully consistent with the theoretical predictions of the Multiflux Framework.

5 Licensing and Modeling Implications

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6 Conclusion

We have presented the first numerical evidence for the Multiflux Theory using fully synthetic and fully spectral HIT fields up to 384^3. The stable convergence to $N_{\text{eff}} = 12$ suggests that multiflux decomposition may capture a fundamental structural feature of turbulent flows.

Future work includes analyzing DNS datasets from JHTDB, performing GPU-based high-resolution tests, and exploring temporal evolution of the subflux field.

References

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