Application of a Multifractal Phenomenological Model of Atmospheric Turbulence to Elastic Lidar Data

Iulian Alin Roșu[1], Marius Mihai Cazacu 2[2], Maricel Agop 3[2,3]
[1]Școala Doctorală a Facultății de Fizică, "Universitatea Alexandru Ioan Cuza" din Iași
[2]Departamentul de Fizică, Universitatea Tehnică Gheorghe Asachi din Iași
[3]Academia Oamenilor de Știință din România, București
alin.rosu@student.uaic.ro

Research Motivation

This work shall present a coupling of a multifractal turbulence model with a phenomenological model of turbulent flow structure applied to real data. The objective is to construct an improved phenomenological turbulence model using theoretical considerations regarding multifractal structures through non-differentiable functions in the form of an adaptation of scale relativity theory.

Methodology of Research

The minimal vortex of an instance of turbulent flow is considered, leading to a general equation for the non-differentiable vortex itself with its component velocity fields, and to energy dissipation. Then, an improved phenomenological turbulence model and relations between it and the minimal vortex are employed together, exemplifying the codependency of such models. Using turbulent medium wave propagation theory, certain relations are then extrapolated which allow the obtaining of the inner and outer length scales of the turbulent flow using lidar data.

Results and Comparison with State-of-the-art

In order to construct this phenomenological model, the parameters that govern scale behavior during the energy cascade need to be complex numbers. The model requires three initial scales, and yields realistic values and varying Hausdorff dimensions for the vortices described by the calculated scales, which illustrate the multifractal structure of the turbulent flow. The calculated altitude profiles are compiled and assembled into timeseries to exemplify the theory and are compared favorably with known literature.

Conclusions

A novel interpetation of turbulent structures in the context of modified turbulence phenomenology yields realistic and favorable results, driving new questions regarding the nature of turbulence.

Keywords: turbulence; multifractal; bifurcations

Domain: physics
Section: New (2020) thesis proposals

References

Badii, R. (1997). *Complexity: Hierarchical Structures and Scaling in Physics*. Cambridge University Press.

Nottale, L. (2011). *Scale relativity and fractal space-time: a new approach to unifying relativity and quantum mechanics*. World Scientific.

Agop, M., Paun, V.P. (2017). *On the new perspectives of fractal theory. Fundaments and applications*. Bucharest: Romanian Academy Publishing House

Roșu, I. A., Cazacu, M. M., Ghenadi, S. A., Bibere, L., & Agop, M. (2020). On a multifractal approach of turbulent atmosphere dynamics, *Frontiers in Earth Science*, 8, 216.

Mandelbrot, B. B. (1983). *The fractal geometry of nature (Vol. 173)*. New York: WH Freeman.

Baker, G. L., Gollub, J. P. (1996). *Chaotic Dynamics: An Introduction*, New York: Cambridge University Press.

Cristescu, C. P. (2008). *Nonlinear dynamics and chaos. Theoretical fundaments and applications*. Romanian Academy Publishing House.

Boffetta, G., Mazzino, A., & Vulpiani, A. (2008). Twenty-five years of multifractals in fully developed turbulence: a tribute to Giovanni Paladin. *Journal of Physics A: Mathematical and Theoretical*, 41(36), 363001.

Benzi, R., Paladin, G., Parisi, G., & Vulpiani, A. (1984). On the multifractal nature of fully developed turbulence and chaotic systems. *Journal of Physics A: Mathematical and General*, 17(18), 3521.

Tatarski, V. I. (2016). *Wave propagation in a turbulent medium*. Courier Dover Publications.

Rosu, I. A., Cazacu, M. M., Prelipceanu, O. S., & Agop, M. (2019). A Turbulence-Oriented Approach to Retrieve Various Atmospheric Parameters Using Advanced Lidar Data Processing Techniques. *Atmosphere*, 10(1), 38.

Belegante, L.; Cazacu, M.M.; Timofte, A.; Toanca, F.; Vasilescu, J.; Rusu, M.I; Ajtai, N.; Stefanie, H.I; Vetres, I.; Ozunu, A.; Gurlui, S. (2015). Case study of the first volcanic ash exercise in Romania using remote sensing techniques. *Environmental Engineering & Management Journal (EEMJ)*, 14(11), 2503-2504.

Papayannis, A.; Nicolae, D.; Kokkalis, P.; Binietoglou, I.; Talianu, C.; Belegante, L.; Tsaknakis, G.; Cazacu, M.M.; Vetres, I.; Ilic, L. (2014). Optical, size and mass properties of mixed type aerosols in Greece and Romania as observed by synergy of lidar and sunphotometers in combination with model simulations: A case study. *Science of The Total Environment*, 500-501, 277-294.

Roșu, I. A., Ferrarese, S., Radinschi, I., Ciocan, V., & Cazacu, M. M. (2019). Evaluation of Different WRF Parametrizations over the Region of Iași with Remote Sensing Techniques. *Atmosphere*, 10(9), 559.

Yura, H.T. (1979). Signal-to-noise ratio of heterodyne LIDAR systems in the presence of atmospheric turbulence. *Opt. Acta Int. J. Opt.*, 26, 627-644.

Liu, Z.; Hunt, W.; Vaughan, M.; Hostetler, C.; McGill, M.; Powell, K.; Winker, D.M.; Hu, Y. (2006). Estimating random errors due to shot noise in backscatter lidar observations. *Appl. Opt.*, 45, 4437–4447.

***, Hamamatsu; (2007). Photomultiplier Tubes, and Photomultipliers Tubes Photonics "Basics and Applications"; Hamamatsu Photonics KK: Iwata City, Japan.

Chen, W.Y (1974). Energy dissipation rates of free atmospheric turbulence. *Journal of the Atmospheric Science*, 31(8), 2222-2225.

Shupe, M.D., Brooks, I.M., Canut, G. (2012). Evaluation of turbulent dissipation rate retrievals from Doppler cloud radar. *Atmospheric Measurement Techniques*, 5(6), 1375-1385