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Editorial

Structure of Atmospheric Turbulence

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Turbulence is a phenomenon observed in the motions of fluids and gases. This phenomenon occurs in different mediums and conditions. In a turbulent state, the motions of various spatial scales are excited (from the largest scales associated with the boundary conditions of flow to the smallest fluctuations corresponding to the viscous dissipation. In spite of a number of achievements in the study of turbulent flows, a full theory of turbulence has not been developed. The full theory of turbulence is still a challenge for modern physics and mathematics.

The importance of turbulence research is also determined by problems in aerodynamics, hydraulics, chemical production, geophysics, atmospheric physics, astronomy and other fields of science.

The theory of atmospheric turbulence continues to develop rapidly. A lot of papers are devoted to studies of energy spectra of atmospheric turbulence under different thermal stratification of the atmosphere and over complex underlying surfaces.

This Special Issue of *Atmosphere* entitled "Structure of Atmospheric Turbulence" contains six papers.

The paper "Turbulence in Large-Scale Two Dimensional Balanced Hard Sphere Gas Flow" is aimed at the study of turbulent motions as well as the transition from a laminar regime of flow to turbulence [1]. The author has studied the possibilities of the original model of a balanced compressible hard-sphere gas flow to describe the generation of turbulent motions for the two-dimensional case. In particular, features in the spectral structure of two-dimensional motions have been discussed. In an inertial jet, the energy spectrum of turbulence is shown to obey the "$-5/3$" power law in the intermediate range of scales and the "$-8/3$" power law for small scales. The power laws estimated in the paper are in good agreement with the previously obtained shapes of spectra. Abramov R.V. [1] noted that in the two-dimensional cyclostrophic vortex, the "$-5/3$"slope of the energy spectrum is observed over the full spectral range. Usually, vortex structures are characterized by a spectrum slope close to -3 [2,3].

The paper "Vertical Shear of the Horizontal Wind, Jet Streams, Symmetry Breaking, Scale Invariance and Gibbs Free Energy" describes the study of turbulent atmosphere energetics [4]. The variations in the vertical scaling exponent of the horizontal wind with altitude are discussed. Dependencies of scaling exponent on the difference between the maximum and minimum of wind speeds as well as air temperatures are analyzed. The scaling exponent increases as these differences increase. It is also interesting to note that the scaling exponent tends to increase with the growth of the depth of the jet stream. In the paper, the results indicate that the persistence of molecular velocity after collision induces symmetry-breaking emergence of hydrodynamic flow.

The paper "A Survey of Structure of Atmospheric Turbulence in Atmosphere and Related Turbulent Effects" is devoted to the study of the structure of atmospheric Kolmogorov and non-Kolmogorov turbulence [5]. In particular, the authors claim that atmospheric turbulence is Kolmogorov in the lower layers of the atmosphere. In higher layers of the atmosphere, turbulence is non-Kolmogorov. In the study, the authors analyze various dependencies of the spectral density of fluctuations on frequency in the troposphere and stratosphere.

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As applied to astronomy, the features of spectral variations of optical turbulence are considered in the paper "Energy Spectra of Atmospheric Turbulence for Calculating C_n^2 Parameter. I. Maidanak and Suffa Observatories in Uzbekistan" [6]. Optical turbulence is a phenomenon associated with the fluctuations in air density at different altitudes in the atmosphere [7–10]. These studies were carried out at the sites of astronomical observatories Maidanak and Suffa. These astronomical observatories are located at the best sites in Eurasia. Using an analysis of the spectral structure of large-scale turbulence the characteristic slopes of the energy spectra of fluctuations in wind speed and air temperature were estimated. These spectra often differ from classical shapes. Energy spectra obtained are often lower-pitched. Spectra do not correspond to dependencies of power spectral density of fluctuations on frequency: f^{-3}. The spectral dependencies can be used in estimations of the statistics of small-scale turbulence using fluctuations in meteorological parameters, including the C_n^2 parameter.

In the paper "Wander of a Gaussian-Beam Wave Propagating through Kolmogorov and Non-Kolmogorov Turbulence along Laser-Satellite Communication Uplink", the authors proposed exponential power spectra of refractive index fluctuations for non-Kolmogorov turbulence in the free troposphere and the stratosphere [11]. Authors developed a three-layer altitude-dependent model of the power spectrum of refractive-index fluctuations for satellite-to-ground and ground-to-satellite links, which is composed of the exponential Kolmogorov turbulence power spectrum of the boundary layer, the exponential non-Kolmogorov power spectrum turbulence of the free troposphere, and the exponential non-Kolmogorov power spectrum of the stratosphere.

Nowadays a lot of papers present the results related to optical turbulence profiling [12–16]. The last paper presents "Method for Measuring the Second-Order Moment of Atmospheric Turbulence" [17]. Shen H. et al. discuss the method to measure the characteristics of optical turbulence. The authors propose a method for measuring the second-order moment of atmospheric turbulence. The authors estimate the number of parameters and errors using $C_n^2(z)$ profiles (Middle East, GreenWood, Clear 1, Hap, SLCnight, H-V 5/7). Using the method, the authors estimate the second-order moment of atmospheric turbulence μ_2 which is useful for the analysis of integrated tip-tilt and isokinetic angle. Moment μ_2 can also be monitored as a routine parameter such asμ_0 (Fried parameter) and $\mu_{5/3}$ (isoplanatic angle).

Thus, the issue contains a number of new results from original studies of atmospheric turbulence, including an analysis of the spectral structure of turbulent fluctuations in different ranges. Interesting methods have been proposed for measuring and studying atmospheric and optical turbulence. The results obtained may be of interest for atmospheric physics and optics, meteorology, and astronomy, including issues related to the development of adaptive optics systems [18].

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References

1. Abramov, R.V. Turbulence in Large-Scale Two-Dimensional Balanced Hard Sphere Gas Flow. *Atmosphere* **2021**, *12*, 1520. [CrossRef]
2. Nosov, V.V.; Kovadlo, P.G.; Lukin, V.P.; Torgaev, A.V. Atmospheric coherent turbulence. *Atmos. Ocean. Opt.* **2013**, *26*, 201–206. [CrossRef]
3. Gkioulekas, E.; Tung, K.-K. Recent Developments in Understanding Two-dimensional Turbulence and the Nastrom–Gage Spectrum. *J. Low Temp. Phys.* **2006**, *145*, 25–57. [CrossRef]
4. Tuck, A.F. Turbulence: Vertical Shear of the Horizontal Wind, Jet Streams, Symmetry Breaking, Scale Invariance and Gibbs Free Energy. *Atmosphere* **2021**, *12*, 1414. [CrossRef]
5. Wang, F.; Du, W.; Yuan, Q.; Liu, D.; Feng, S. A Survey of Structure of Atmospheric Turbulence in Atmosphere and Related Turbulent Effects. *Atmosphere* **2021**, *12*, 1608. [CrossRef]
6. Shikhovtsev, A.Y.; Kovadlo, P.G.; Kopylov, E.A.; Ibrahimov, M.A.; Ehgamberdiev, S.A.; Tillayev, Y.A. Energy Spectra of Atmospheric Turbulence for Calculating C2n Parameter. I. Maidanak and Suffa Observatories in Uzbekistan. *Atmosphere* **2021**, *12*, 1614. [CrossRef]
7. Masciadri, E.; Vernin, J.; Bougeault, P. 3D mapping of optical turbulence using an atmospheric numerical model. I. A useful tool for the ground-based astronomy. *Astron. Astrophys. Suppl. Ser.* **1999**, *137*, 185–202. [CrossRef]
8. Hagelin, S.; Masciadri, E.; Lascaux, F. Optical turbulence simulations at Mt Graham using the Meso-NH model. *Mon. Not. R. Astron. Soc.* **2011**, *412*, 2695–2706. [CrossRef]
9. Abahamid, A.; Vernin, J.; Benkhaldoun, Z.; Jabiri, A.; Azouit, M.; Agabi, A. Seeing, outer scale of optical turbulence, and coherence outer scale at different astronomical sites using instruments on meteorological balloons. *Astron. Astrophys.* **2004**, *422*, 1123–1127. [CrossRef]
10. Sánchez García, R.; Richer, M.G.; Gómez Martínez, R.; Avila, R. Estimating local seeing at Observatorio Astronómico Nacional in San Pedro Mártir using CFD simulations of the atmospheric boundary layer. *Mon. Not. R. Astron. Soc.* **2020**, *496*, 5552–5563. [CrossRef]
11. Wang, F.; Du, W.; Yuan, Q.; Liu, D.; Feng, S. Wander of a Gaussian-Beam Wave Propagating through Kolmogorov and Non-Kolmogorov Turbulence along Laser-Satellite Communication Uplink. *Atmosphere* **2022**, *13*, 162. [CrossRef]
12. Wilson, R. SLODAR: Measuring optical turbulence altitude with a Shack–Hartmann wavefront sensor. *Mon. Not. R. Astron. Soc.* **2002**, *337*, 103–108. [CrossRef]
13. Butterley, T.; Wilson, R.; Sarazin, M. Determination of the profile of atmospheric optical turbulence strength from SLODAR data. *Mon. Not. R. Astron. Soc.* **2006**, *369*, 835–845. [CrossRef]
14. Osborn, J.; Wilson, R.; Butterley, T.; Shephard, H.; Sarazin, M. Profiling the surface layer of optical turbulence with SLODAR. *Mon. Not. R. Astron. Soc.* **2010**, *406*, 1405–1408. [CrossRef]
15. Shepherd, H.W.; Osborn, J.; Wilson, R.W.; Butterley, T.; Avila, R.; Dhillon, V.S.; Morris, T.J. Stereo-SCIDAR: Optical turbulence profiling with high sensitivity using a modified SCIDAR instrument. *Mon. Not. R. Astron. Soc.* **2014**, *437*, 3568–3577. [CrossRef]
16. Wang, Z.; Zhang, L.; Kong, L.; Bao, H.; Guo, Y.; Rao, X.; Zhong, L.; Zhu, L.; Rao, C. A modified S-DIMM+: Applying additional height grids for characterizing daytime seeing profiles. *Mon. Not. R. Astron. Soc.* **2018**, *478*, 1459–1467. [CrossRef]
17. Shen, H.; Yu, L.; Jing, X.; Tan, F. Method for Measuring the Second-Order Moment of Atmospheric Turbulence. *Mon. Not. R. Astron. Soc.* **2021**, *12*, 564. [CrossRef]
18. Lukin, V.P.; Antoshkin, L.V.; Bol'basova, L.A.; Botygina, N.N.; Emaleev, O.N.; Kanev, F.Y.; Konyaev, P.A.; Kopylov, E.A.; Lavrinov, V.V.; Lavrinova, L.N.; et al. The History of the Development and Genesis of Works on Adaptive Optics in the Institute of Atmospheric Optics. *Atmos. Ocean. Opt.* **2020**, *33*, 85–103. [CrossRef]