‘On dissipation time scales …’ preprint, response to Anonymous Referee #2

Review by Anonymous Referee #2 (https://editor.copernicus.org/index.php?_mdl=msover_md&_jrl=778&_lcm=oc108lcm109w&_acm=get_comm_sup_file&_ms=117323&c=260754&salt=13916850601854574235).

Authors' response in italics, highlighted by light grey colour.

This review references detailed comments to the line(s) in the manuscript.

GENERAL

This paper, like many others in the two centuries that have elapsed since Navier first formulated equations of fluid flow and the one and a half since Stokes corrected them, stumbles on the closure problem and on the concept of dissipation. It is my contention that application of the Langevin equation to the atmosphere results in the conclusion that the emergence of fluid flow and dissipation are intimately linked at the molecular level. References [1,2,3,4] have argued so; "Direct Numerical Simulation" should really entail this approach rather than some arbitrary scale assumption.

We would like to thank the reviewer for the interest in our paper and for the valuable comments.

COMMENTARY

17-18: In a coupled nonlinear system like the atmosphere, "control” is a slippery concept. Particularly when the real atmosphere's boundaries are far less restrictive than those employed here. Laminar flow of any sort is not to be found in the air, let alone such an artificial system such as Couette flow.

We performed a series of DNS of stably stratified turbulent plane Couette flow for a wide range of Reynolds numbers defined by the wall velocity difference, channel height, and kinematic viscosity, up to Re = 120 000. Within this range of the Reynolds number, a shear-produced fully-developed turbulence has been produced in DNS. In the atmosphere, nonuniform wind is one of the primary sources of shear-produced fully-developed turbulence.

31: Kolmogorov's theory has been reformulated for the atmosphere; see for example [5,6].

35-41: "Closure” betrays the real difficulty. The need for a bottom up, molecular approach has been largely ignored, but was pointed out in [1,2,3].

45-50: See references [7,8,9] for a discussion of Ri.

The classical Kolmogorov theory of fully-developed turbulence was originally formulated for neutrally stratified homogeneous isotropic turbulence. Many turbulence closure models of stratified turbulence in meteorological applications have been based only on the density of the turbulent kinetic energy equation, without considering the evolution of the density of the turbulent potential energy proportional to the second moment of potential temperature fluctuations. In stable stratification, such turbulence closure models have led to the erroneous conclusion that shear-generated turbulence inevitably decays, and that the flow becomes laminar under "supercritical" stratifications (with the gradient Richardson number exceeding certain critical value). Contradictions of this conclusion, evidenced by the well-documented universal existence of turbulence under strongly supercritical conditions typical of the free atmosphere and the deep ocean, have been attributed to some unknown mechanisms and, in practical applications, handled heuristically.

We are uncertain about the feasibility of employing a molecular approach to describe velocity and temperature fluctuations in the inertial range of scales for fully-developed turbulence with large Reynolds numbers. Based on our current understanding, molecular simulations incur significant computational costs and may only be practical for small Reynolds numbers.

60-79: The debate about dissipation ignores the reality of the Langevin equation and the approach to dissipation that emerges from a bottom up, molecular dynamics approach [4,10,11].

153 et seq: Couette flow has little physical reference to any atmospheric flow. The boundary conditions are far too restrictive. DNS is not direct. Molecular dynamics would qualify and is now almost within reach of current computational performance.

205: "dissipation time scale" is covering some major difficulties. See [4,10,11].

299-316: Dissipation is the process defining an operational temperature; it is infrared radiation to space.

The effects discussed in Refs. [4,10,11], mentioned in the Referee report, are too different from those discussed in our paper. Contrary to Refs. [4,10,11], we consider a simpler system that does exclude humidity, radiation and photochemical effects, as well as phase transitions, cloud formation, and related physics. We have not studied complicated effects related to the intermittency of air temperature and its correlation with ozone photo-dissociation rate and the diurnal variation of ozone in the upper stratosphere.

We study a classical idealised problem of stably stratified shear-produced turbulence. In DNS, we use Couette flow for simplicity, because it allows us to *perform well-controlled numerical experiments. It assures a very certain fixed value of the Obukhov length scale, because in Couette flow the total (turbulent plus molecular) vertical fluxes of momentum and potential temperature are constant (i.e., they are independent of height). Our paper is relevant to the well-developed turbulence regime, where molecular transport is negligible compared to turbulent transport, so that turbulent fluxes practically coincide with total fluxes.*

REFERENCES

1. von Neumann, J. L. Recent Theories of Turbulence, in Collected Works of John von Neumann, Vol. 6, pp. 437-472, Macmillan, 1963.

2. Grad, H. Principles of the Kinetic Theory of Gases, in Handbuch der Physik, Band 12, S. Flugge, ed., pp. 205-294, Springer Verlag, Berlin, 1958.

3. Tuck, A. F. ATMOSPHERIC TURBULENCE: A Molecular Dynamics Perspective. Oxford University Press, Oxford, 2008.

4. Tuck, A. F. Scaling up: molecular to meteorological via symmetry breaking and statistical multifractality. Meteorology, 1, 4-28 (2022)

5. Schertzer, D.; Lovejoy, S. Physical modeling of rain and clouds by anisotropic scaling multiplicative processes. J. Geophys. Res. D, 92, 9693-9714 (1987).

6. Lovejoy, S.; Schertzer, D. The Weather and Climate: Emergent Laws and Multifractal Cascades. Cambridge University Press, Cambridge, UK. (2013).

7. Lovejoy, S.; Tuck, A. F.; Hovde, S. J.; Schertzer, D. Is isotropic turbulence relevant in the atmosphere? Geophys. Res. Lett. 34, L15082 (2007).

8. Lovejoy, S.; Tuck, A. F.; Hovde, S. J.; Schertzer, D. Do stable atmospheric layers exist? Geophys. Res. Lett. 35, L01802 (2008).

9. Hovde, S. J.; Tuck, A. F.; Lovejoy, S.; Schertzer, D. Vertical scaling of temperature, wind and humidity fluctuations: dropsondes from 13 km to the surface of the Pacific Ocean. Int. J. Remote Sensing 32, 5891-5918 (2011).

10. Tuck, A. F. Turbulence: vertical shear of the horizontal wind, jet streams, symmetry breaking and Gibbs free energy. Atmosphere, 12, 1414 (2021).

11. Tuck, A. F. Air temperature intermittency and photofragment excitation. Meteorology, 2, 445-463 (2023).

RECOMMENDATION

If the journal wishes to continue the largely unsuccessful grappling with turbulence that has characterized the last two centuries, then publish this paper -

it is better than most of the genre. But if so, the authors should acknowledge, however briefly, some of the difficulties outlined above.