

# **October 2012: Institute of Environmental Physics, IUP**

## **Special Lecture-Series No. 5,**

### **“Molecules to Meteorology”**

**(ATMOSPHERIC TURBULENCE: A Molecular Dynamics Perspective)**

**Lecturer 2012: Professor Dr. Adrian Tuck**

**Location: Room S1360, Building NW1, University of Bremen Otto Hahn Allee 1, 28359, Bremen**

**Dates: 02.10.2012 to 12.10.2012 14:00 to 16:00hrs**

**02.10.2012 14:00 – 16:00 Introduction Implications for radiative transfer & chemistry slides**

**04.10.2012 14:00 – 16:00 Kinetics, fluid mechanics and scale invariance and vertical scaling of observations**

**08.10.2012 14:00 – 16:00 Horizontal scaling of observations and Correlations among scaling exponents**

**10.10.2012 14:00 – 16:00 Consequences [1] and [2]**

**12.10.2012 14:00 – 16:00 Molecular dynamics, scale invariance & natural selection and Key points and what to do about them.**

**The lecturer – Professor Adrian Tuck**

Professor Adrian Tuck is a graduate of the Universities of Manchester and Cambridge in the United Kingdom. After postdoctoral studies at the University of California, San Diego, he joined the UK Met Office where amongst other responsibilities he was the scientific lead in the 1970's and early 1980's in the development of the UK

Meteorological Research Flight's atmospheric chemistry capability, which provided measurements of trace atmospheric constituents of fundamental importance, a forerunner of the modern European research fleet. He then moved to the NOAA Aeronomy Laboratory in Boulder Colorado in 1986. He was responsible at NOAA for pioneering studies of the earth atmosphere. He led the very successful ER-2 and DC-8 aircraft campaigns which uniquely showed the role of Chlorofluorocarbons in the complex physico chemical mechanism which results in the ozone hole over Antarctica and more recently over the Arctic. From 1997 he led the use of the WB57F



## **ATMOSPHERIC TURBULENCE**

A Molecular Dynamics Perspective



ADRIAN F. TUCK



in the study of exchange between the stratosphere and troposphere, and in the real time chemical analysis of individual aerosol particles. He initiated the use of the Global Hawk for atmospheric research. After returning to the United Kingdom in 2008 he is now a Visiting Professor in Physics at Imperial College London and was Professeur Invité, École Nationale des Ponts Paris-Tech, Université de Paris-Est.

### **The course abstract: Molecules to Meteorology**

The material in these five 2-hour lectures draws on work published in the literature during the previous thirteen years, applying Schertzer and Lovejoy's theory of generalized scale invariance to a large body of airborne data which showed atmospheric variability well above instrumental noise levels but which could not be described adequately by Gaussian PDFs and second moment power spectra.

The atmosphere is molecules in motion but a lacuna exists as regards explicit discussion or treatment of this fact in the meteorological literature and among standard texts on dynamic meteorology, fluid mechanics, turbulence, multifractals, non-equilibrium statistical mechanics and kinetic molecular theory. The wind blows, with core velocities in upper tropospheric jet streams reaching 30% of the most probable molecular velocity, and up to 70% in the upper stratospheric polar night jet stream defining the winter vortex. Under such circumstances, Maxwell-Boltzmann distributions of molecular speeds cannot exist.

While texts on atmospheric chemistry of course deal in molecular behaviour, the step from kinetic molecular theory to atmospheric motion is made often without comment, usually via application of the law of mass action on scales many orders of magnitude larger than the mean free path and on which true diffusion cannot be dominant.

Discussions of the progression from molecular to fluid motion are found mainly in the statistical mechanics literature but with no consideration of complicated anisotropic large-scale flows within morphologically irregular boundaries, such as those the atmosphere exhibits. There are few examples of attempts to examine the molecular roots of turbulence. These lectures aim to point out the need to address this situation, and to offer suggestions about how to proceed, with close attention to analysis of observational results.

The central point of these lectures is that molecular dynamics, via the generation of vorticity in the presence of anisotropies such as gravity, planetary rotation and the solar beam, influences the structure of turbulence, temperature, radiative transfer and chemistry in the atmosphere. Because energy is deposited in the atmosphere by molecules absorbing photons, energy must propagate upward from the smallest scales. Analyses are presented of observations by the statistical multifractal methods developed by Schertzer and Lovejoy, which show generalized scale invariance in the atmosphere. The need to unite molecular dynamics, turbulence theory, fluid mechanics and non-equilibrium statistical mechanics is reinforced by the fact, mentioned above, that core wind speeds in jet streams can reach significant fractions of the most probable velocity of air molecules, a breach of the conditions under which

standard derivations of the Navier-Stokes equation are made. Note that in saying this I do not intend to imply that continuum fluid mechanics needs major reformulation in the context of the meteorological simulation of the large-scale flow by numerical process on computers for weather forecasting; the enterprise is too demonstrably successful for that to be the case. Indeed, some understanding of the success of this operation emerges naturally from analyzing high-resolution observations in a statistical multifractal framework. However, for representing the smaller scales, and for accurate accounting of the detailed energy distribution in the atmosphere, required for climate prediction, turbulence must be properly understood and formulated. It is my contention that it will not be achieved without explicit recognition of the fact that fluid mechanical behaviour emerges spontaneously in the molecular dynamics simulation of a population of Maxwellian molecules subject to an anisotropy; turbulence has molecular roots.

Some key references are given below.

## Literature

- 1) Alder & Wainwright (1970), Phys. Rev. A, 1, 18-21.[emergence of fluid flow from molecular dynamics]
- 2) Schertzer & Lovejoy (1987), J. Geophys. Res., 92, 9693-9714.[generalized scale invariance, statistical multifractals]
- 3) Tuck (2010), Q. J. R. Meteorol. Soc., 136, 1125-1144.  
[review]
- 4) Hovde, Tuck, Lovejoy & Schertzer (2011), Int. J. Remote Sensing, 32, 5891-5918, doi: 10.1080/01431161.602652. [latest on vertical scale invariance]
- 5) Pinel, Lovejoy, Schertzer & Tuck (2012), Geophys. Res. Lett., 39, doi: 2012GL051689.[latest on horizontal scale invariance]
- 6) Tuck, "Atmospheric Turbulence: A Molecular Dynamics Perspective", Oxford University Press, 2008, ISBN 978-0-19-923653-4.
- 7) Lovejoy & Schertzer, "The Weather and Climate: Emergent Laws and Multifractal Cascades", Cambridge University Press, October 2012, ISBN-13: 9781107018983.