Scientific Report

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Colloquium N0 561 Scientific Report

One of the most remarkable features of turbulence is that it operates in a radically different way in two-dimensional (2D) flows than it does in three-dimensional (3D) flows. Whilst the former is characterised by an inverse energy cascade that sees larger, less dissipative structures emerge, the latter tends to very efficiently dissipate energy by transferring it to small scales where it is dissipated by viscous friction.

The question of whether turbulence obeys two or three-dimensional dynamics therefore has drastic consequences for the natural and industrial processes where it is involved. This concerns numerous classes of realistic systems under the influence of rotation, stratification or magnetic fields as well as in purely 2D geometrical configurations. The tendency to two-dimensionality in stratified flows and rotating flows is a prominent feature of planetary flows such as atmospheres and oceans. This feature has also been observed in electrically conducting flows under a strong magnetic field (MagnetoHydroDynamic flows), extending the relevance of the question of flow dimensionality to astrophysical and laboratory plasma flows (for instance, the understanding of particles and heat flux dynamics in the magnetic-field transverse directions has tremendous importance in the achievement of thermo-nuclear fusion), but also to liquid-metals engineering problems in the nuclear and metallurgical industries. The common tendency to two-dimensionality, however, hides a variety of physical mechanisms: the propagation of inertial waves along the rotation axis promotes two-dimensionality in rotating flows, while eddy currents induced play this role in MHD flows, by generating Alfven waves if magnetic advection is important (in plasmas for instance), or by diffusing momentum along the field if it isn't (as often in liquid metals). In magnetized plasmas, drift waves play a leading role in momentum transport perpendicular in the directions perpendicular to the magnetic field. Their dynamics share many characteristics with inertial (Rossby) waves, both modelled by the Charney-Hasegawa-Mima equation. The geometry of the fluid domain too can favour either 2D or 3D dynamics, in particular if it is very thin along one direction, as in Hele-Shaw cells, or soap films. Nevertheless, the question of dimensionality of turbulence is conditioned by a number of features that are common to these systems: the boundaries are part of the very definition of the concept of two-dimensionality.

The Colloquium was very successful in gathering researchers from these different communities, all confronted to the problem of dimensionality. In particular, dimensional transition were extensively discussed in the context of

- “Classical” hydrodynamic turbulence confined in plane layers bounded by physical walls or other boundary conditions.

- Rotating flows, in particular in geophysical context

- Stratified turbulence, also in geophysical context, relevant to geophysical flows. The occurrence of the “zig-zag” instability distinguishes this type of flow from others as it can lead to a rather unique “pancake” structure.

- Liquid metal MHD, where the tendency to two-dimenisonality follows form a diffusive process

- convective flows, where two-dimensional plumes can form also under the influence of any of the forces above.

A number of talks focused on the properties of 2D turbulence versus those of 3D turbulence. The colloquium clearly showed that the competition between these two types dynamics takes place in a rather similar fashion in most of the physical systems that were mentioned. For example, striking features such as split energy spectra exhibit simultaneously a direct and an inverse cascade over different ranges of wavenumbers were a recurring feature of flows in intermediate states between purely 2D and 3D ones. The fact that similar features take place in systems driven by different underlying physical mechanisms suggests that the dimensional properties of these flows are very robust. Nevertheless, it seems difficult to draw one general picture covering all systems (Stratified flows, exhibit mechanisms quite unlike rotating and MHD flows)

The colloquium was also very successful in exposing complex examples where several of these basic phenomena are involved and compete to determine flow dimensionality:

- rotating convection

- flows in geophysical context, in particular those relevant to dynamo problems (this involve various combinations of rotation, MHD and convection.)

- Astrophysical flows

In conclusion, the meeting fully achieved its objective of initiating inter-disciplinary discussions around a unifying theme, and took place in excellent spirit. Excellent feedback from the participants suggests that a second meeting in the mid term (say 3-4 years) is likely to attract similar or even larger attendance.