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Scaling properties of irreversibility indices in turbulence

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In 3D turbulence there is a flux of energy from large to small scales in the inertial range, associated with irreversibility, i.e. a breaking of the time reversal symmetry (Pumir, 2016). Such turbulent flows are characterized by scaling properties and we consider here how irreversibility depends on the scale. Two indicators of irreversibility for time series are tested involving triple correlations in a non-symmetric way. The first one proposed by Pomeau (1982, 2004) is: $Po(r)=<X(t)X(t+r)X(t+3r)>-<X(t)X(t+2r)X(t+3r)>$, where r is an increment and X(t) is the turbulent velocity which is stationary with zero mean. The second indicator has been proposed in the finance literature (Ramsey and Rothman, 1996), and was called symmetric bicovariance function: $y(r) = <X^2(t)X(t+r)>-<X(t)X^2(t+r)>$. For time reversible processes, both indicators are zero, whereas their departure from 0 is an indicator of irreversibility.

We study these indicators applied to fully developed turbulence time series, from flume tank, wind tunnel and atmospheric turbulence databases. It is found that irreversibility occurs in the inertial range and has scaling properties with slopes close to one. A maximum value is found around the injection scale. This confirms that the irreversibility is associated with the turbulent cascade in the inertial range and shows that the irreversibility is maximal at the injection scale, the largest scale of the turbulent cascade.

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