SELF-SIMILAR REGIMES IN UNSTABLY STRATIFIED HOMOGENEOUS TURBULENCE

Alan Burlot[1], Benoît-Joseph Gréa[1], Jérôme Griffond[1] & Olivier Soulard[1]
[1]*CEA, DAM, DIF, F-91297 Arpajon, France*

Abstract Unstably stratified homogeneous turbulence develops at late time a self-similar dynamics characterized by an exponential growth of turbulent quantities. It is believed from recent theoretical studies that different growth rates are possible, depending on the initial distribution of energy at large scales. In order to confirm these predictions, we run both highly resolved direct numerical simulations and a spectral model based on an eddy-damped quasi-normal closure. In addition to confirming the influence of initial conditions, our study sheds light on the anisotropic structures of the self-similar regimes.

In many problems, the initial distribution of energy at large scales influences the late time dynamics of turbulent flows. A classical illustration of this phenomenon is the self-similar decay of homogeneous isotropic turbulence (HIT) in which the decay rate, as shown first by (1), depends on the properties of large scale eddies. This effect has been also identified in more complex flows such as buoyancy induced turbulence (2). Quite recently in (5), these ideas were transposed to a new problem, how to evaluate the growth rates of self-similar regimes in unstably stratified homogeneous turbulence (USHT). Therefore, assuming that the infrared spectrum representing large scale properties in the kinetic energy spectrum $E(k)$ scales as $\sim k^s$, the kinetic energy $\mathcal{K}(t)$ evolves self-similarly at late time t as $\sim e^{\beta N t}$ with N the buoyancy frequency (similar to Brunt-Väisälä frequency in stably stratified flows). A strong result of the theory is an explicit expression for the growth rate coefficient β, related to the infrared slope as:

$$\beta = \frac{4}{s+3} \text{ for } s \leq 4. \tag{1}$$

Unfortunately, it is hard to confirm these predictions as the self-similar states of USHT are generally difficult to observe. Indeed, an important characteristic of USHT is the growth of the integral scale which at late time (see Fig. 1) generally induces confinement effects in experiments (6) and direct numerical simulations (4). In order to deal with this issue, we have developed a specific method for USHT based on an eddy-damped quasi-normal Markovian (EDQNM) closure (3). This model tries to take into account different specific features of the flow: To begin with, the spectra depend explicitly on the angle between the wave vector and the vertical direction to evaluate the effect of directional anisotropy. Also, we include in the eddy-damping term the buoyancy frequency N to express the modifications of energy transfer due to sweeping effects between structures of different buoyancies. In addition to this spectral model, we performed highly resolved direct numerical simulations with different infrared slopes which allow to explore the beginning of the self-similar regime. Our study will show in particular that:

- The measures of the different growth rate confirm the validity of Eq. 1 (see Fig. 2).
- The self-similar regimes have different anisotropic structures for the buoyancy and turbulent velocity field.

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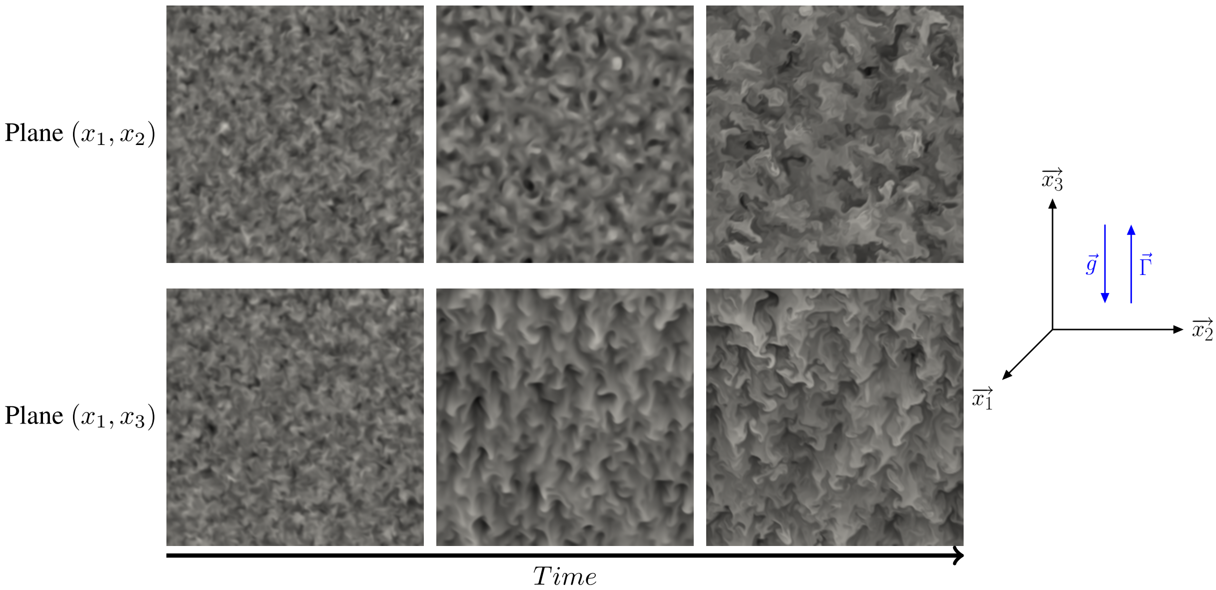

Figure 1. Visualizations of the fluctuating buoyancy field extracted from DNS in USHT at different times and for vertical and horizontal planes .

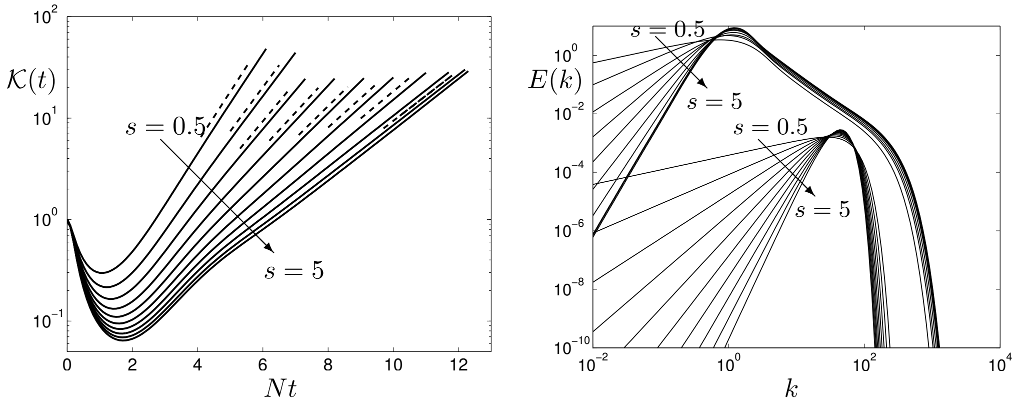

Figure 2. (Left): Time evolution of the kinetic energy. Each curve corresponds to different initial infrared exponent s. The slopes for the different dashed straight lines corresponds to the theoretical β of Eq. (1). (Right) Spectra of kinetic energy at initial time and at a given turbulent Reynolds number ($\simeq 46000$). Initial conditions have been divided by a factor 10 to fit correctly in the figure.