Abstract

Clouds are complex phenomena present in the atmosphere. Their description is complicated by the presence of many processes in atmospheric flows occurring at different scales. Cumulus, which are a common type of cloud present all over the world, are a manifestation of convective motions. Their evolution and development is influenced by mixing with the environment, as well as by intra-cloud mixing, both of which are highly turbulent.

Due to the limited resolution in weather models, the effects associated with turbulence, especially turbulence that does not fully satisfy the assumptions of Kolmogorov theory, are not correctly represented. In addition, due to the need for more accurate parameterisations, it is useful to divide areas of the atmosphere into those with specific dynamic properties.

As part of this work, analyses of data gathered during EUREC^{4}A campaign near Barbados in 2020 were carried out. Data consisted of three components of wind velocity, temperature and liquid water content. Analyses were carried in the context of turbulent mixing in clouds. First, a number of sections were selected to represent the different physical situations present in the atmosphere. The segments represent the simple trajectory of an aircraft at a given altitude. Because they are one-dimensional and have a finite resolution of the order of one metre, the possibilities of analysing turbulence properties are somewhat limited.

Because cumulus clouds constitute only a portion of a flight segment, special care had to be taken in selecting the size of the window for Reynolds decomposition, and the size of a window over which the statistics were calculated. These sizes influence the values of the quantities which characterise turbulence. A selection of parameters was made using the maximisation criterion, based on the sensitivity study. This was followed by analyses of the turbulence kinetic energy dissipation rate ε, the integral length scale L and the Taylor microscale λ, as fundamental quantities characterising the turbulent flow. As expected, elevated values of ε occurred in and around clouds. The integral length scale ranged from 20 to 50 metres. A decreased value of Taylor microscale correlated with the presence of the clouds.

In the case of the atmosphere, turbulence is produced at multiple loca-

tions by different mechanisms operating at different scales. For this reason, the Kolmogorov theory of locally isotropic and stationary turbulence, often assumed in model parameterisations and analyses, has the right not to be fulfilled. Therefore, analyses were carried out for the departure of turbulence from isotropy, by means of proportionality coefficient analysis, together with the use of the turbulence triangle method. No clear correlation was found between a specific turbulence state and the presence of clouds, but from the results it can be concluded that turbulence reaches the entire spectrum of anisotropy states at medium scales. Morover, analyses of nonequilibrium turbulence were performed, based on recent theoretical studies. Overall results show that C_ε, a parameter which quantifies the turbulence equilibrium decreases in clouds.

Next, in order to construct conditional statistics, a time-dependent recurrence quantification analysis was performed. This method is usually used in the dynamical systems context. It revolves around an analysis of the recurrencies of a vector in the phase space. Based on that, a recurrence matrix can be constructed, and a further analysis of its properties can be performed. One obtains a set of parameters which quantify a segment of a trajectory. Here, a time-dependent version of the recurrence quantifiaction analysis was done in order to obtain time series of the parameters. Analogously a sensitivity study was done in order to determine what are the best values of parameters in this context. The results shown a decrease in the values of certain parameters inside clouds and their surroundings.

Finally, based on a selection of a critical value of one of the parameters, a method to distinguish segments was proposed. The division distinguished segments with different dynamical properties, and different properties of turbulence. The portions of the flight representing clouds and their surroundings had similar properties in terms of turbulence, as opposed to other regions.