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Multifractal Analysis of Velocity Vector Fields and a Continuous In-Scale Cascade Model

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In this study we have compared the multifractal analyses of small-scale surface-layer wind velocities from two different datasets. The first dataset consists of six-months of wind velocity and temperature measurements at the heights 22, 23 and 43m. The measurements came from 3D sonic anemometers with a 10Hz data output rate positioned on a mast in a wind farm test site subject to wake turbulence effects. The location of the test site (Corsica, France) meant the large scale structures were subject to topography effects that therefore possibly caused buoyancy effects.

The second dataset (Germany) consists of 300 twenty minute samples of horizontal wind velocity magnitudes simultaneously recorded at several positions on two masts. There are eight propeller anemometers on each mast, recording velocity magnitude data at 2.5Hz. The positioning of the anemometers is such that there are effectively two grids. One grid of 3 rows by 4 columns and a second of 5 rows by 2 columns.

The ranges of temporal scale over which the analyses were done were from 1 to 10^3 seconds for both datasets. Thus, under the universal multifractal framework we found both datasets exhibit parameters $\alpha \approx 1.5$ and $C_1 \approx 0.1$. The parameters α and C_1, measure respectively the multifractality and mean intermittency of the scaling field. A third parameter, H, quantifies the divergence from conservation of the field (e.g. $H = 0$ for the turbulent energy flux density). To estimate the parameters we used the ratio of the scaling moment function of the energy flux and of the velocity increments. This method was particularly useful when estimating the parameter α over larger scales. In fact it was not possible to obtain a reasonable estimate of alpha using the usual double trace moment method.

For each case the scaling behaviour of the wind was almost isotropic when the scale ranges remained close to the sphero-scale. For the Corsica dataset this could be seen by the agreement of the spectral exponents of the order of 1.5 for all three components. Given we have only the horizontal wind components over a grid for the Germany dataset the comparable probability distributions of horizontal and vertical velocity increments shows the field is isotropic.

The Germany dataset allows us to compare the spatial velocity increments with that of the temporal. We briefly mentioned above that the winds in Corsica were subject to vertical forcing effects over large scales. This means the velocity field scaled as 11/5 i.e. Bolgiano-Obukhov instead of Kolmogorov's. To test this we were required to invoke Taylor's frozen turbulence hypothesis since the data was a one point measurement. Having vertical and horizontal velocity increments means we can further justify the claims of an 11/5 scaling law for vertical shears of the velocity and test the validity of the Taylor's hypothesis.

We used the results to first simulate the velocity components using continuous in-scale cascades and then discuss the reconstruction of the full vector fields.