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Fractal Dropsonde Trajectories and Anomalous Turbulence Exponents

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Much of our knowledge about the structure of the atmosphere is obtained by in situ measurements: aircraft, radiosondes and more recently, dropsondes. However turbulence, especially in the wind field affects these measurement platforms by altering the trajectories of measuring devices; they are no longer along straight horizontal or vertical sections; indeed, a model of turbulence is required in order to interpret the measurements. For example, if the turbulence is isotropic in three dimensional space, then one expects (at least naively) that unique exponents will exist and - at least as far as the scaling exponents are concerned - that the nonrectilinear trajectories are unimportant. Similarly, in 2D isotropic turbulence, the vertical structure is too smooth to lead to biases. However, if the turbulence is anisotropic (neither 3D nor 2D) - and growing evidence shows that it is indeed in between with D?2.55 - then the trajectories can perturbed over long ranges; recently (Lovejoy et al 2004) have shown that aircraft can have fractal trajectories and anomalous (horizontal) scaling exponents over hundreds of kilometers. In this paper, we investigate the corresponding problem for state-of-the-art dropsondes and the implications for the vertical structure of the atmosphere. Dropsondes measure temperature, humidity and pressure as they fall through the troposphere. The velocity is estimated by accurately tracking their position using GPS followed by a correction using a simple dynamical model of how the sonde responds to the wind. We analyzed the vertical statistics using structure functions and spectra. The scaling was generally found to be excellent; figure 1 shows a typical example using an ensemble of 24 dropsondes; the scaling extending from at least 3m to over a kilometer (it is still accurate up to nearly 10km).

Fig. 1a: First order structure function of the potential temperature , H??0.85 (straight line). Units of z are meters. Fig. 1b: First order structure function of the nominal horizontal sonde velocity , Hv?0.81 (straight line). Units of z are meters.

In fig. 1b, we show the corresponding figure for the nominal horizontal velocity, i.e. calculated according to the standard algorithm. It can be seen that although the scaling is excellent, that the exponent (Hv=0.81) is anomalous, being considerably higher than the Kolmogorov value 1/3, and even somewhat higher than the Bolgiano-Obukov value 3/5 (as expected in the 23/9D anisotropic model; the value Hv=0.81 corresponds to an energy spectrum with (ignoring small intermittency corrections) ?v?1+2 Hv =2.62). In order to understand these anomalous velocity statistics, we used a simple dynamical model of the sonde with quadratic wind resistance and uniform gravity. For the wind field, we used an anisotropic multifractal model. We show that the sonde velocity statistics can be explained by the anisotropic extension of Kolmogorov's law in accord with the 23/9D model.

References: Lovejoy, S., D. Schertzer, and A. F. Tuck, 2004: Fractal aircraft trajectories and nonclassical turbulent exponents, Physical Review E, 70, 036306-1-5.