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Reinterpreting aircraft measurements in anisotropic scaling turbulence

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Due to unavoidable vertical fluctuations, the interpretation of atmospheric aircraft measurements requires a theory of turbulence. Until now virtually all the relevant theories have been isotropic. However almost all the available data on the vertical structure shows that it is scaling but with exponents different from the horizontal: the turbulence is anisotropic not isotropic. In this paper, we show how this can lead to spurious breaks in the scaling and to the spurious appearance of the vertical scaling exponent at large horizontal lags.

We demonstrate this using 16 legs of Gulfstream 4 tropospheric data following isobars each between 500 and 3200 km in length. First we show that the horizontal spectra of the aircraft altitude are nearly k-5/3 (although smoothed by aircraft inertia at scales < 3 km). In addition, we show that the altitude and pressure fluctuations along these fractal trajectories have a high degree of coherence with the measured wind (especially with its longitudinal component). There is also a strong phase relation between the altitude, pressure and wind fluctuations with all of these effects occurring over the entire range of scales so that the trajectories influence the wind measurements over large ranges of scale. In comparison, the temperature and humidity have no apparent scale breaks and the corresponding coherencies and phases are low reinforcing the hypothesis that it is the aircraft trajectory is causally linked to the scale breaks.

Using spectra and structure functions we then estimate the small and large scale exponents finding that they are close to the Kolmogorov values (5/3, 1/3) and the vertical values (2.4, 0.73) (for respectively the spectral and real space scaling exponents (, H)) which are close to those estimated by drop sondes (2.4, 0.75) in the vertical direction. In addition, for each leg we estimate the energy flux, the sphero-scale and the critical transition scale. The latter varies quite widely from scales of kilometers to greater than several hundred kilometers. We theoretically explain this behaviour by considering the absolute slopes of the aircraft as a function of lag. Finally, we revisit four earlier aircraft campaigns including GASP and MOZAIC showing that they can be very easily explained by the proposed combination of altitude/wind and anisotropic but scaling turbulence.