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Aircraft measurements of the horizontal multiplicative cascade structure of the atmosphere

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Statistical theories of atmospheric dynamics are based on assumptions of scaling, isotropy and the existence of a scale by scale conserved quantity, typically the energy or (quasi) enstrophy flux. Due to the atmospheric scale height, isotropic turbulence cannot hold over very wide ranges of scale so that existing purely isotropic turbulence models predict different large scale 2D and small scale 3D regimes. However drop sonde and lidar studies of have shown that the vertical is scaling but with different exponents than the horizontal. The resulting anisotropic turbulence can therefore be scaling over much wider ranges – in principle over the entire meteorologically significant range. This prediction of wide range multiplicative cascades starting at planetary scales has recently been directly confirmed in numerical models of the atmosphere and in remotely sensed radiances. Since the latter are nonlinearly coupled with the dynamics this is indirect support for the cascade model.

In this talk we discuss the first direct (in situ) empirical confirmation of multiplicative cascade models using aircraft data using 16 legs of Gulfstream 4 tropospheric data following isobars each between 500 and 3200 km in length. The analysis is complicated by the coupling of the aircraft trajectory with the fields being measured. This is because in anisotropic but scaling turbulence, vertical fluctuations in aircraft altitude can lead to the appearance of vertical fluctuation exponents in apparently horizontal analyses, hence to spurious breaks in the horizontal scaling. We determine scaling exponents and external scales characterizing the cascade structure for temperature, potential temperature, humidity, longitudinal and transverse wind, and pressure. We find that the main quantity affected by the aircraft trajectory is the wind field, especially the longitudinal wind which we show has fluctuations highly coherent with altitude fluctuations. As expected, the external scales are close to the size of the planet and the exponents are significantly smaller than in the vertical confirming the strongly anisotropic nature of the cascade dynamics. These results can be applied to the statistical evaluation of numerical models the atmosphere and their (stochastic) parametrisation.