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The Space-time evolution of atmospheric structures: the role of the vertical velocity

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There is still no clear empirical picture of the temporal scaling of the horizontal wind or of passive scalars; in particular, there is evidence for energy spectra E(ω) $\approx$ $\omega^{-\beta}$ with both β $\approx$5/3 and β $\approx$ 2 exponents. While the former is explained with the usual Kolmogorov or Corrsin-Obukov theory coupled with the assumption of "frozen turbulence" (horizontal wind domination), the classical explanation for the β $\approx$ 2 exponent is via dimensional analysis based on the Eulerian-Lagrangian similarity hypothesis (pure temporal development, negligible wind). However, in laboratory flows Tennekes argued that due to the "sweeping" of the small eddies by the larger ones, that the $\omega^{-5/3}$ wind behaviour should be dominant for all time scales below the eddy turn over time (lifetime) of the largest eddies. Since in the atmosphere, it now seems that the scaling continues up to planetary scales - with corresponding eddy turn over times of about two weeks - this implies that for time scales below this that one should observe β $\approx$5/3 rather than β $\approx$ 2. In other words, the classical theory does not give a cconvincing explanation for the numerous cases of ω^{-2} scaling over much shorter time scales.

However Tennekes assumed that turbulence was isotropic whereas it is anisotropic, requiring the framework of generalised scale invariance (GSI). This anisotropic space-time scaling framework indeed gives another possible explanation of the β $\approx$ 2

behaviour: it is the result of scaling vertical velocities. This is possible because unlike the horizontal wind which has a well defined mean over a large region, the vertical velocity fluctuates around zero, converging to zero in a (presumably) scaling way as the space-time scale of the averaging increases. Taking into account intermittent nature of the vertical velocity and assuming that the mean vertical wind (w) over time scale Δt scales as $w \approx \Delta t^H$ with the plausible assumption that $H \approx$ -0.1 theory yield a spectral scaling exponent close to 2.

We investigate this issue using state-of-the-art lidar data of passive scalars and from meteorological analyses using the regional GEM model analyses (Meteorological Service of Canada). GSI theory allows the analyses to be used to estimate the critical time scales at which the vertical wind behaviour ($\beta \approx 2$) will dominate the horizontal behaviour ($\beta \approx 5/3$). We find that the cumulated probability that the critical time for horizontal-to-vertical transition is less than 10^2 s is 5% while the same probability of horizontal-to-time transition accumulates only at lags of $\sim 3\times10^4$ s, at which probability of horizontal-to-vertical transition is $\sim$40%. Thus it is unlikely to that we will observe pure temporal domination at times in the range 10^2s to 10^4s while there is a reasonable probability of observing vertical wind domination. This gives a straightforward explanation of the $\beta \approx 2$ value occasionally cited in the literature and found in some of our lidar data sets.