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Scaling behaviors in the cascade process of atmospheric turbulence

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From the works of Kolmogorov in 1941, it has been generally recognized that the homogeneous and isotropic turbulence transfers the energy step by step from larger scales to smaller scales. This process, called cascade, can be displayed by the measurable probability density functions (PDFs) where the forms of PDFs change from fat-tailed distributions to Gaussian distribution with the increase of scales. Fat-tailed distributions mean that the cascade process at smaller scales is intermittent. Atmospheric turbulence, affected by diurnal variations, complex terrain and other factors, is generally non-stationary, non-homogeneous and non-isotropic. However, recent evidences show that atmospheric turbulence has a similar transformation of PDFs with the increase of scales, even up to mesoscales. It means that a cascade process may also exist in non-homogeneous and non-isotropic atmospheric turbulence.

Two models, the truncated stable model and log-normal model, have been used to describe this cascade process in atmospheric turbulence. Both models have the transformation of PDFs with the variations of scales and can fit the observed PDFs well. In this paper, however, further study shows that both models are in fact not good models for describing atmospheric cascading process. Here, we focus on the scaling behaviors of atmospheric turbulent velocity increments which display the cascading process in another view. Two kinds of scaling behaviors, the scaling behaviors of the probability of return and the higher-order moments are studied and we find that the above-mentioned models both have some problems. The truncated stable model can produce a power law of probability of return but the power exponent is too large to fitting the data. One possible reason is that this model can only describe the independent random process while statistical correlations always exist in the time series of atmospheric turbulent velocity increments. The truncated stable model can also produce a power law of moments. The power exponents vary as a bi-linear function of order, while the observed exponents are concave. The log-normal model seems to be better than the truncated stable distribution. Under some conditions, its exponents vary as a parabola function which can fit the data well. However, this model cannot fit the probability of return and the moments at the same time either. Our study may be helpful for understanding the underlying cascade process in atmospheric turbulence.