Non-Gaussian Tracer Distributions from Horizontal Advection

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Observed surface tracer distributions are non-Gaussian, which has implications for the likelihood of extreme events in a changing climate. We use an idealized model of horizontal tracer advection by eddies to explore the reasons for the non-Gaussianity, with a particular focus on skewness. We begin with temperature, which is treated as a passive tracer. We demonstrate that even in the presence of a Gaussian flow field and a linear temperature gradient, significant skewness exists in the temperature distribution. We examine how the distribution changes with changes to the background temperature gradient and the thermal relaxation timescale, and to eddy properties including wavenumber, location and phase speed. These parameters are simplified versions of changes that are expected with climate change: arctic amplification will decrease the equator to pole temperature gradient, the thermal relaxation timescale will depend on large scale moisture fluxes, and the eddy properties are related to the change of the position and the character of the midlatitude jet and tropospheric baroclinicity. To first order, the temperature skewness is independent of the temperature gradient. The background temperature gradient sets the variance, and the flow field sets the skewness. These results demonstrate a compensation between the effects of the shift of the midlatitude jet and the decreased meridional temperature gradient on the likelihood of extreme heat events in the future climate. We extend this analysis to an idealized chemical tracer with a first-order loss in order to explore the reason that chemical tracers exhibit distributions that are positively skewed, such as log normal and Weibull distributions, while temperature distributions can have both positive and negative skewness. Simple scaling arguments are employed to demonstrate the relationships among the parameters that lead to this difference.

Key words: atmospheric transport, extreme heat events, extreme pollution events