Energetics and Rotational Dynamics of Hurricane Clusters

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A sequence of new results are presented, some theoretical, others analytical, of the energetics and dynamics of cloud clusters within a hurricane, imaged by a ground-based radar.

A similarity structure for the energetics, for a hurricane as a whole, is first postulated, based on a theoretical analysis of the relative roles of latent heating and dissipation, within a field of moist convection, based on the results of Pauluis and Held (2002), considered in terms of the observed probability density function (pdf) of reflectivity for a single image of Hurricane Irma. The ratio of energy generation and removal, which is termed the convective intensity, is key to distinguishing categories of the strength of convection, evidenced in the pdf - ranging from mixed sensible and latent heating to ultimate full latent heating.

Considerable radar meteorology research has established well-known empirical relationships between reflectivity and the (beam averaged) terminal velocity, droplet size, and rain rate, which allows for estimates of dissipation, energy, and ultimately entropy. In this description of the hurricane's energetics at pixel scale, the convective intensity is synonymous with the 'temperature' of what amounts to a statistical dynamics model of the rain field.

Two methods are offered to estimate the convective intensity from the imagery. The first is through the creation of a simple physical model for the rain rate which, when compared to its estimates from its radar

imagery estimate, isolates the latent heating. The second is the computation of the convective intensity from the Gibbs distribution (e.g. Kerman, 1998) of the pixel-to-pixel differences in energy, with the additional assumption that the informational entropy involved is proportional to the model’s entropy. Both estimates agree well over the convective range of reflectivity where the latent heating exceeds sensible heating. From this comparison, an empirical relationship is derived which allows for an explicit estimate of the convective intensity of a pixel directly from the reflectivity field.

The synonymous relationship between the convective intensity and ‘temperature’ allows for a computational annealing (Press et al., 1989) of the image into ‘clusters’. This process mirrors the ‘cooling schedule’ used in the metallurgical annealing procedure in which locations of lower temperature, not hitherto attached, are attached to a warmer one, from the warmest to the coolest. The result is about 12k clusters in an image of some 140k precipitating pixels, of which 3-5k clusters are large enough to provide reliable estimates of their statistical structure. For example, the resulting exponential pdf of their sizes agrees with other studies (e.g. Simpson, 1972) of (visible, distinct) cumulus cloud sizes. Further analysis is provided by the summed energetics of these clusters which shows how the various energetics and the convective intensity are distributed over the entire imaged field.

A very useful concept, entropic forces, is next borrowed from other physical processes (e.g. description of a heterogeneous field of colloids). That formulation is shown to further decompose into the two basic classes of forces in meteorological dynamics –irrotational (divergent/convergent) and rotational (spin). Statistically the force fields over a pixel are shown to be gamma distributed and functions of the convective intensity.

The two new techniques, annealing and entropic forces, are combined by summing over a cluster the implied shear stress around, and convergence into, individual pixels. The observed simultaneous existence within a cluster of counter-rotating sub-clusters suggests that there exists some self-similar process, ultimately related to the spatial distribution of local latent heating and dissipation.

A basic relationship between energy generation by latent heating and cluster rotation follows from dimensional analysis. By extension, one expects that the removal of energy at the dissipation rate also controls the removal of angular momentum. The ratio of positive rotational momentum in all such sub-clusters to the sum of all rotation momentum in all sub-clusters is shown empirically to be proportional to the ratio of angular momentum generated by latent heating and that removed by dissipation.

The similarity constant between theses ratios is found to be 0.66 +/- 0.026 (based on a constrained sample of 14 clusters with sizes greater than 25 pixels in order to retain sufficient numerical accuracy). Combined with other simple empirical relationships for the ratio of positive and negative as well as total and positive rotation rates in terms of the convective intensity, it is possible to extract the angular rotation rates for the sub-clusters and combined cluster, and combined size of the sub-clusters, given the convective intensity and total cluster size.

In the future, it is planned to follow the time evolution and vertical structure of individual clusters. A multivariate probit method of cluster identification in subsequent, or adjacent height, images has been tested and will be applied to invariant/similar properties of individual annealed clusters.

It is remarked for interest, based on an analysis of the fractal dimension of categorized reflectivity, that a Richardson (1926) dispersion process is possibly present for the pixelated image, and has a characteristic exponent of 4/3 for weak convection and 5/3 for large convective intensity locations. A tentative model involving evolution and rotation associated with the latent heating rate suggests that there may exist angular momentum exchange in a stochastic field of rotating clusters.

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