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Research Article

Rotation, Convectivity and Hurricane State Determined by Entropic Forces: *Relevance to AI Methodology*

Bryan Kerman*

Retired, Ontario, Canada

Abstract

The concept of entropic forces is introduced to demonstrate a new method to calculate the convective state of a cluster in rain clouds, associated with hurricanes and tornados. A derivation of these internal cloud forces, involving the ratio of the angular speed and terminal velocity of rotating clouds, compared to convectivity, which characterizes the ratio of latent heating and dissipation rates, has been shown to adequately characterize a hurricane's state. The existence and properties of the entropic forces driving the associated dynamics are shown to reveal the interactive conditioning of the individual clouds by the ratio of rotational momentum, and that of the release of heat upon condensation, to that by turbulent dissipation. The method requires a microwave/millimeter radar to locally compute the foundational properties before derivation of the overall hurricane state. *Statement of Importance:* A potential link between AI and entropic forces has been suggested by others. By the definition, offered by IBM 'Artificial intelligence, or AI, is technology that enables computers and machines to simulate human intelligence and problem-solving capabilities'. In this paper, it is demonstrated that there is a computational algorithm which translates remotely sensed, strongly convectivity imagery into a numerical statement of 'hurricane state', and one which further uses simple mathematical statements of deduced forces in radar imagery. It is further deduced that the current AI computation of hurricane state from a GOES satellite should be extended to isolate radial flow in such rotating areas. It may also be that such areas have a locally different radiational temperature associated with local overshooting within a cluster.

Keywords

Hurricane, Entropic Forces, Rotation, Convectivity, Artificial Intelligence

1. Introduction

It is well-known that the rain field and convective clouds are associated with a number of major threats to safety - from hurricanes, and tornadoes of different scales. Explanation of the creation of rotation in the atmosphere using Newtonian (energetic) forces is complicated from a dynamic and computational approach. However, by focusing on the entropic dynamics, characterizing 'organized chaos' in the rain field, the result is a highly structured picture of the dynamics, and a very much simpler measurement method. A number of papers [1-5, 10, 11] have studied various aspects of dissipative heating, characteristic grouping, the role of moisture in convection, latent heating in determining convective structure, especially clustering and the size distribution of such convection associated with self-organization.

The concept of entropic forces was first introduced by Neumann as an alternative method of considering random

*Corresponding author: bkerman@lara.on.ca (Bryan Kerman)

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mixtures and their associated structures in atomic physics [8]. Such forces have since been applied in formulations in fields as dissimilar as hydrophobics, polymers, astronomy, gravity, dark matter, colloidal mixtures, and biological cell structures [13]. From a meteorological point of view, Holloway [6] considered qualitatively their hypnotized presence in synoptic scale atmospheric dynamics. Wisser-Gross and Free [15] argued, in a controversial paper, that there was an inter-relationship between entropic forces and 'artificial' intelligence. [12, 14] Recently, the author has demonstrated the existence of entropic forces in clouds, particularly convective hurricane and tornado clouds [7] and their use in computing hurricane state in terms of a (convective) Rossby number..

The following note is meant to extend and clarify those entropy-based applications involving strong convection, as in hurricanes and tornadoes, It is hoped that the discussion will be useful in evaluating AI solutions for the same purpose.

2. Computation of Entropic Forces in Convection

The classical equation ('Wikipedia', [7]) for (vector) entropic forces is a reconsideration of the classical, thermodynamics' definition of a force (acceleration) in terms of (unit-less) 'temperature' and (kinetic) energy

$$\vec{a}_e = T\frac{\partial S}{\partial \vec{x}} = \frac{\partial E}{\partial \vec{x}} \quad (1)$$

It will be demonstrated that there is an alternative atmospheric formulation involving entropy which is based on an alternative definition of 'temperature' in convection. While temperature obviously initiates and drives convection, it is shown that a thermodynamic property (convectivity), vital to the control of the vertical and lateral cloud growth, and for the creation of rotation within a cloud, is also needed. It has been argued, that the equivalent of temperature is a measurement of the convectivity.

Pauluis and Held [9] closely examined the convectivity in a hurricane. They argued that a measure of cloud convectivity, i.e. the ratio of energy generated as a result of the release of heat by condensation of water vapor (L), relative to its dissipation rate of mechanical turbulence (D), denoted [4] by the ratio, was essential to understanding 'wet entropy' dynamics. Kerman found μ to be both calculatable from hurricane (radar) imagery, and to be extremely valuable, as an essential indicator of the state of convection in hurricane clouds - once a method, involving deduced properties (rain rate, terminal velocity, and rain drop size) in the turbulent convective rain field, based on radar observation, were identified and computed. From that experience, it was realized that a method was needed to express previously (unknown/unrecognized) entropic forces in a non-Newtonian manner.

$$\mu = \frac{L}{D} \quad (2)$$

Examination of the basic definition of entropic forces [13] led the author to the realization that such a general formulation might prove useful in a chaotic rain field, if computable. Previous experience by the author, with an alternative derivation of chaos, involving Gibbs distributions of energy differences in hurricane imagery, with coefficients correlated to the turbulent energy level at test locations, led to a postulated 'state' relationship, which switched temperature

$$\vec{a}_e = \frac{\partial \mathrm{E}}{\partial \vec{x}} = T\frac{\partial \mathrm{S}}{\partial \vec{x}} \quad (3)$$

as utilized in classical thermodynamics, to some measure of chaos (convectivity) required for an appropriate entropi c force definition expressed by

$$\vec{a}_e = \frac{\partial \mathrm{E}}{\partial \vec{x}} = \mu\frac{\partial \mathrm{S}}{\partial \vec{x}} \quad (4)$$

From the classical relationship, it is clear that the result of substituting ($T \leftrightarrow \mu$) leads to a valid relationship as long as the entropy and energy are co-located, making their space-time derivatives interchangeable. With that proviso, expansion of Eq. 4 results in the definition of entropic acceleration/force relationship given by

$$\vec{a}_e = \frac{1}{2}\left(\frac{\partial V_T^{\,2}}{\partial z} + \frac{\partial V_T^{\,2}}{\partial r} - V_T^{\,2}\frac{\partial \ln \mu(r)}{\partial r}\right) \quad (5)$$

Upon further expansion of the kinetic energy, in terms of the terminal velocity in the falling rain, $E = v_T^2/2$, and its relationship to S, results in the basic relationship between entropic forces within the perimeter of a cluster, given by

$$\vec{a}_e = \frac{1}{2}\left(\frac{\partial V_T^{\,2}}{\partial \vec{x}} + V_T^{\,2}\frac{\partial \ln \mu}{\partial \vec{x}}\right) \quad (6)$$

where 3-dimensional directionality is implied. It is useful to point out that the acceleration in any direction is controlled by the gradients of the terminal velocity and the convectivity. In addition, the convectivity at a given height varies by both advective (lateral external wind field, which is not consider here) and outward, radial diffusive kinetic energy mixing, and its conversion to rotational energy associated with the azimuthal variability of the rain field. Consider a partial expansion of Eq. 6, re-written to capture the principal directionality of each component of the convectivity, the total forces are based on the assumptions that:

a) The convectivity is strong enough to mix the condensed water-vapor laterally.

b) The lateral structure of the actual rain field is controlled by an upward supply of condensation nuclei, so that the principal factor, the rain rate, is largest at the center of a convective cloud. From Eq. 6, the radial component reduces to

$$\vec{a}_e = \frac{1}{2}\left(\frac{\partial V_T^{2}(z)}{\partial z} + \frac{\partial V_T^{2}(r)}{\partial r} - V_T^{2}\left(\frac{\partial \ln \mu(r)}{\partial r} + \frac{\partial \ln \mu(\theta)}{\partial \theta}\right)\right) \quad (7)$$

$$a_r = \frac{E}{\mu}\frac{\partial \mu}{\partial r} = E\frac{\partial \ln \mu}{\partial r} \quad (8)$$

Eq. 8 simply equates the radial entropic force to the energy weighted radial derivative of the natural logarithm of the convectivity.

The relationship between rotation and convectivity of clouds is often taken as a qualitative measure of the state of a hurricane

3. Concentric Field of Vertical Terminal and Horizontal Radial Velocity

The total velocity arises from the cross product of the vertical terminal velocity and the horizontal radial component, expressed by

$$a(x,r,\theta) = \frac{\partial E(z)}{\partial z} + \left(\mu(r)\frac{\partial S(r)}{\partial r} + \mu(\theta)\frac{1}{r}\frac{\partial S(\theta)}{\partial \theta}\right) \quad (9)$$

Eq. 9 is defined at all locations constituting the cluster, The vertical gradient of the kinetic energy (terminal velocity energy) can be computed with data from 2 levels, whereas the radial and azimuthal gradients are computable at each level. The horizontal components reduce to $\frac{1}{r}\frac{\partial E}{\partial \theta}$ and the convectivity rotational and to for $\frac{\partial E}{\partial r}$ the radial.

Calculation of Rotational Entropic Force

While a radar senses areas of precipitation, it does not inherently identify connected, organized cloud areas. A method to extract connected areas of convectivity in terms of connected clusters is required, as discussed next.

1. Simulated Annealing

Simulated annealing mathematically mimics metallurgical annealing involving heated metals cooling sufficiently slowly to define a fine grain arrangement. Computational annealing, logically compares a neighbouring variable which is less than or equal to it in 'temperature', which in the rain field, from the discussion above, is convectivity. Accordingly, a field of clusters represents the area of minimal spatial variation in entropy in the form of minimal convective differences, or conversely maximum spatial density of convectivity.

The computation plan serially identifies neighbouring locations of the current maximal convective pixel, and establishes a connection with any unassigned neighbouring pixel, closest in lesser value, in a growing local cluster. If such a selected pixel has no previously selected neighbour, it becomes the seed for a new cluster. Only when no unattached pixels, above a threshold associated with the boundary between sensible and convective heating, does the annealing end. The clusters are then indexed by their spatial average of μ, i.e. its convective.

2. Cluster Properties

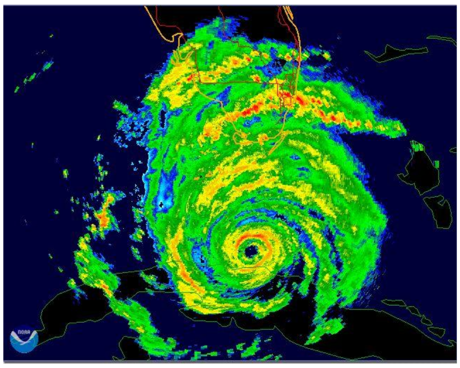

Figure 11. *Surface Radar Image of Hurricane Irma at 00 UDT 09/10/2017.*

Consider a radar scan from Hurricane Irma (Figure 1) which contains about 128k locations/pixels (of approximate side length 0.8 km) indicating precipitation. The results of the annealing process identify only about 12k connected cluster pixels with sufficient convectivity to be dominated by latent heating, i.e. about 10% of the total locations raining.

In addition, the clusters are distributed as shown in Figure 2 which indicates that many clusters are less than about 8-10 pixels in size.

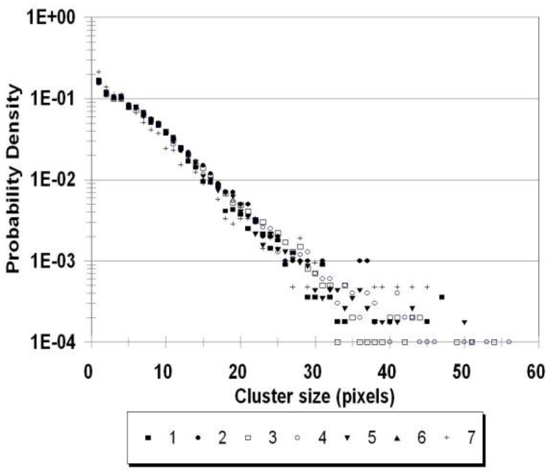

Figure 2. *Size distribution of annealed clusters.*

The first question about these clusters is 'Are they real physical identities?' Proof that they are follows from the observed negative exponential form of their probability distribution for sufficiently large clusters (above 10 pixels), That form is well-known for observed cloud size distributions [5].

The second proof is their coherence, when isolated in radar images at subsequent times, and also at neighbouring heights. The third, and most significant, reason to believe that the organization that connected them, is related to coherent structure arising from the convection, is discussed next.

3. Computation of Cluster Rotation Rate

The rotation rate of convective hurricane clouds is a key measure of the state of a hurricane's energetic state, especially as discussed above in conjunction with azimuthal forces. Surprisingly, the method to isolate such clouds is simple and computationally efficient. In order to extract a rotational velocity of a cluster, differences, tangential to an internal pixel within a cluster, are summed. Next Stokes' relationship is invoked, which equates the areal integral of local horizontal rotational acceleration inside a closed figure with the sum of acceleration on the periphery of the figure, and also its average acceleration in terms of the length of the circumference. Accordingly, at height, z, and radial distance, r, from the clusters vertical center, the (average) rotational acceleration, $\dot{V}_r$, over a cluster, of radius, $r = (C/\pi)^{1/2}$ is given ito it's rotation rate, ω, i.e.

$$\dot{V}_r = \omega^2 r \tag{10}$$

So that the average radial velocity is

$$V_r = \omega r \tag{11}$$

A second method of estimating local average rotation rate follows from the definition of the radial entropic force component - by estimating the RMS azimuthal gradient of the rainfall's kinetic energy, i.e.

$$\left(\omega r^2\right) = rms\left(\frac{\partial E}{\partial \theta}\right) \tag{12}$$

so that the convectivity follows from a simple radial relationship. In addition to its contribution to an understanding of the statistical nature of the inner hurricane flow, Eq. 12, provides another simplified estimate of the effective rotation rate.

4. Computation of the Radial Distribution of Convectivity

Consider next a simplification of the relationship for the radial distribution of the convective flow. By equating the radial energy with the work done by the radial force, i.e., $E_{rad} = r a_{rad}$, the radial force definition, reduces to a simple hyperbolic relation give by

$$\mu = \frac{r_{\min}}{r} \tag{13}$$

in terms of the minimum radius actually rotating, as an alternative method to defining the local effective (dynamic) radius.

4. Hurricane State

The author (Kerman, 2023) found that a useful definition of hurricane state exists; one that is the ratio of the rotation rate, compared to the terminal rain velocity, A ratio of the key parameters, given by

$$\xi = \frac{r_{eff}\,\omega}{V_t} \tag{14}$$

is equivalent to the ratio of the rotational momentum generated to the vertical momentum of the terminal velocity associated with the release of heat energy with the condensation of water vapor, It was demonstrated by the author that (an arbitrarily scaled) ξ closely followed a sampled hurricane (Irma) state from (HRC) hurricane state 4 to state 1 - as it grew prior to landfall and then dissipated as it moved over Florida.

5. Summary

Radar measurements, of either a hurricane (or tornado's) terminal velocity, rain rate, and mean droplet size, can be converted to convectivity at each pixel. The ratio of the rotational and terminal velocities averaged over a cluster produces a snap-shot of the local hurricane state, and, by accumulation and analysis of all clusters, an over-all hurricane state at given time.

While a measure of the average horizontal rotation of (the upper heights of) a hurricane is deduced by AI processing, several problems with adequacy are apparent:

a. At a minimum, the average radial velocity of the rotating, raining area of the hurricane must also be measured to determine the convectivity affecting local hurricane state.

b. The horizontal scale of the convective, rotating clouds in satellite imagery may not be adequate for the determination of a cluster's average radial flow.

It is recommended that an AI based study be made on the much higher resolution ground-based radar data (NEXRAD) in tandem with hurricane state computations based on entropic forces. For example, Hurricane Irma was observed at a radar resolution of about 10 fold, compared to the accompanying GOES imagery, along a long track from Cuba to the South Carolina. The basic objective would be to compare the evolution of hurricane state evaluated using entropic forces and AI methods at the same scale.

Abbreviations

HRC (NOAA)	Hurricane Research Center
NEXRAD	Next Generation Weather Radar

Author Contributions

Bryan Kerman is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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