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Formation of Gravitational Hurricanes Simulated by Numerical Gravitational Gas Dynamics Model

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1. Introduction

The formation and development of hurricanes is of great importance to the forecast centers. Computer simulations essentially improved the forecasts of hurricanes and allow to model their tracks (Dudhia 1993, Grell *et al*. 1994, Zhang *et al*. 2000). The forecasts rely on monitoring real data of satellite atmospheric images (Chelton 2000), Doppler winds (Marks *et al*. 1992), baroclinic disturbances (Davis 2001) and vortices (Kurihara 1998) to detect the hurricanes at the beginning of their formation. However, the simulation models are very complicated (Liu 1999, Tong 2004) including complex parametric schemes for initializing the simulation programs. A more important problem is that there exists no simple physical model for hurricanes and therefore the estimation of their intensity (DeMaria 1994, DeMaria 1999, Camp 2001, Bister and Emanuel 1998) is inadequate and prediction times are relatively short. In this paper we show that density variations in the atmosphere may produce gravitational instability that can lead to the formation of a hurricane. This is a result of a self-gravitational contraction of a slowly rotating gaseous cloud. We developed a gravitational N-body model to simulate the formation and dynamics of a hurricane. The simulation program enables us to predict hurricanes and their intensities at early stages using only two initial parameters, density and velocity. Hurricanes (Holland 1997) are very large sustainable rotating clouds of atmospheric gas with typical size of 1000 km having as usual an eye in the center and spiral arms, whose extreme velocities exceed 30 m/s (Simpson and Riehl 1981). They form above the warm oceans in tropical and subtropical regions (Whitney and Hobgood 1997) and the general conditions favoring their formation have been known for a long time (Gray 1968, McBride and Zehr 1981). Hurricanes are a consequence of the processes in the atmosphere under strong influence of the ocean and the Sun (Merrill 1988, DeMaria 1996). The earth's atmosphere is a very dynamical system. It has been observed that atmospheric pressure, temperature, precipitations and winds including upper winds vary with time (Miller 1958, Malkus and Riehl 1960). Also, variations in angular momentum of the atmosphere can affect the Earth's angular momentum, and consequently, the length of day (Rosen and Salstein 1983, Brzezinski *et al.* 2002). The original model of the hurricane proposed in this paper uses variation of density within the atmosphere resulting in gravitational instability and development of cloud's vorticity. Not only the gravitation of the Earth but also the gravitational interaction between gas molecules plays a very important role in global climate dynamics, particularly, in formation of hurricanes and tropical cyclones.

2. Materials and methods

We consider a numerical modeling of a gaseous cloud using a many-body (N-body) model. The model was used to simulate gravitational systems such as spiral galaxies (Pavlov and Pavlova 2003a) and Saturn (Pavlov and Pavlova 2003b). That model was modified to simulate a self-gravitation of relatively thin disk-like gaseous clouds. The model uses two physical principles - the central gravitational field originating from the center of mass of the cloud and conservation of the angular momentum. In the N-body system, the gravitational force exerting on a *i*th body from all the other bodies is equivalent to a gravitational force from a virtual mass M_i placed in the center of mass. The value M_i depends on the positions of all the bodies relative to the position of the *i*th body. Thus, a whole system is characterized by a set of virtual masses M_i whose values are continuously changing during the simulation due to the change in the relative positions of the bodies.

We simulated the formation of a hurricane as a result of gravitational contraction of the gaseous cloud. The size of the initial cloud is about 2000 km. The algorithm aims for future practical applications. Therefore, we introduced into the simulation 2500 bodies. This number corresponds to a mesh 50x50 with grid spacing 40 km corresponding to a coarse-mesh domain size used for monitoring and computer simulations of the tracks of the hurricanes (Rosenthal 1970). To further simplify the procedure of obtaining the initial conditions, we use randomly distributed positions of the bodies allowing monitoring measurements at random places instead of equally spacing rectangular domains in traditional meshes.

The rotation of the cloud is initiated by the difference in linear movement of the rotating earth's surface when the atmosphere at the equator moves faster than at larger latitudes. There are two observations that help us to understand this process. It is observed that hurricanes are formed outside the equatorial line of around 200 km and rotate counter clockwise in the northern hemisphere and clockwise in the southern hemisphere. If the cloud is formed north from the equator then its northern part moves slower than its southern part and due to the west-to-east general movement of the earth's surface a counter clockwise rotation is generated. Consequently, in the southern hemisphere a clockwise rotation is analogously generated. If the cloud is situated exactly over the equator, then two opposite torques compensate each other. This explains the existence of the calm 200 km-wide equatorial strip.

3. Results

Figure 1 shows the time-evolution of the cloud due to internal gravitational forces only with no influence from the surrounding atmosphere. The cloud has a shape of an elliptical disk. During the gravitational contraction, the disk transforms into a spherical central part and a two-armed spiral. After 2.34×10^5 seconds (65 hours) of the contraction process the eye starts to develop. The eye is a region where the centripetal forces are larger than gravitational ones. The density of the cloud near the eye edge reaches its maximum. Because the density increases faster in the center, this part of the cloud starts to fall downwards the earth's surface (ocean surface) due to the earth's gravitation. This will result in formation of the eyewall. Figure 2 shows the development of the eye in more detail. It is seen that prior to the eye the density in the center increases. This feature can be used as additional indication of hurricanes. During the contraction process, the cloud intensifies reaching the category 1 after 2.50×10^5 seconds. This stage corresponds to the appearance of the eye. With further contraction the hurricane approaches category 2 after 2.7×10^5 seconds, category 4 (3.5×10^5 s.) and category 5 (4.0×10^5 s.) after around 5 days.

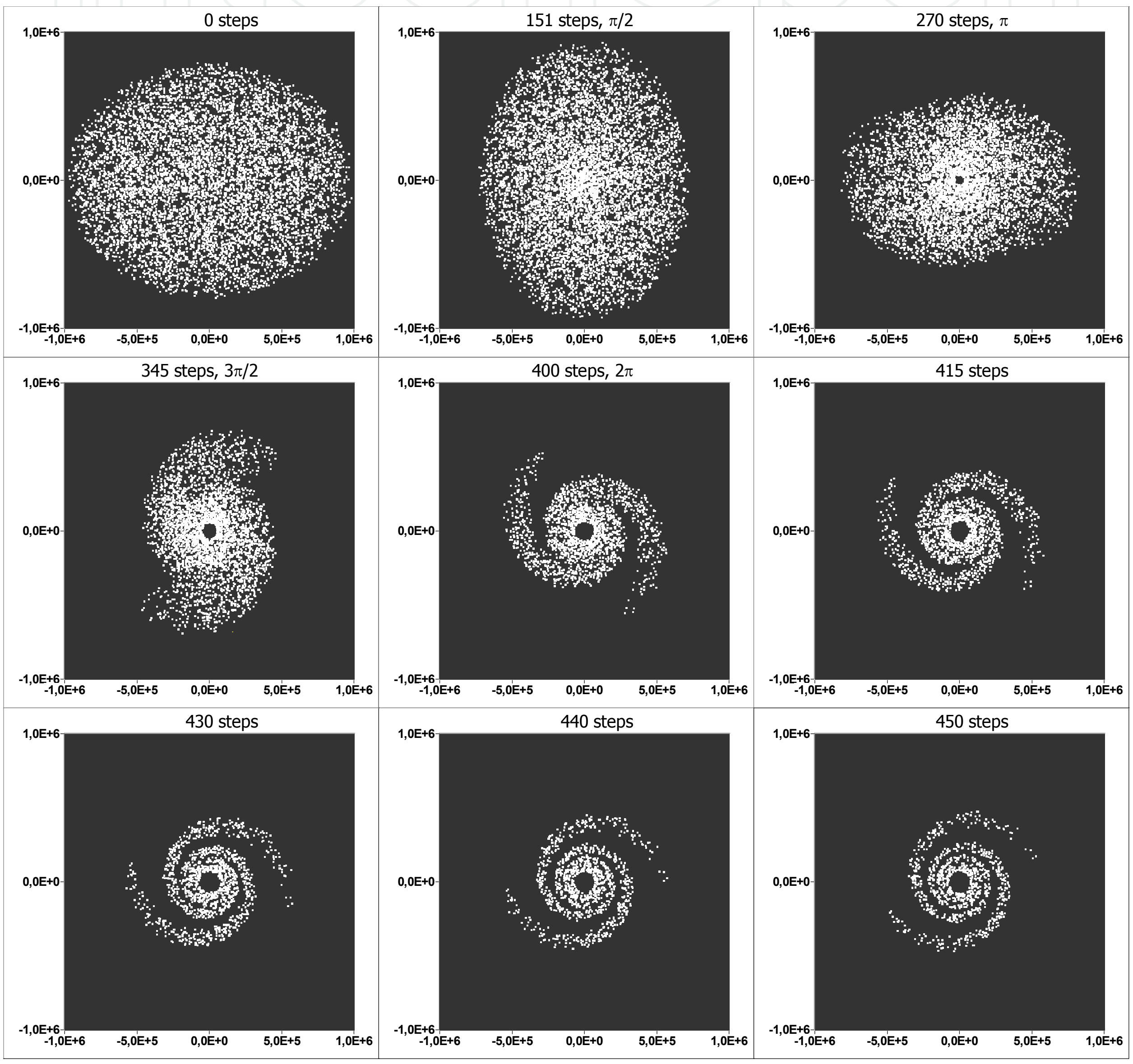

Fig. 1. Time development of the slowly rotating elliptical cloud during self-gravitational contraction. One time step is equal to 1000 seconds. The cloud rotates counter clockwise. The initial angular velocity is 1.0×10^{-5} rad/s. The turning angle shows an average rotation of the cloud relative to the initial orientation of the cloud.

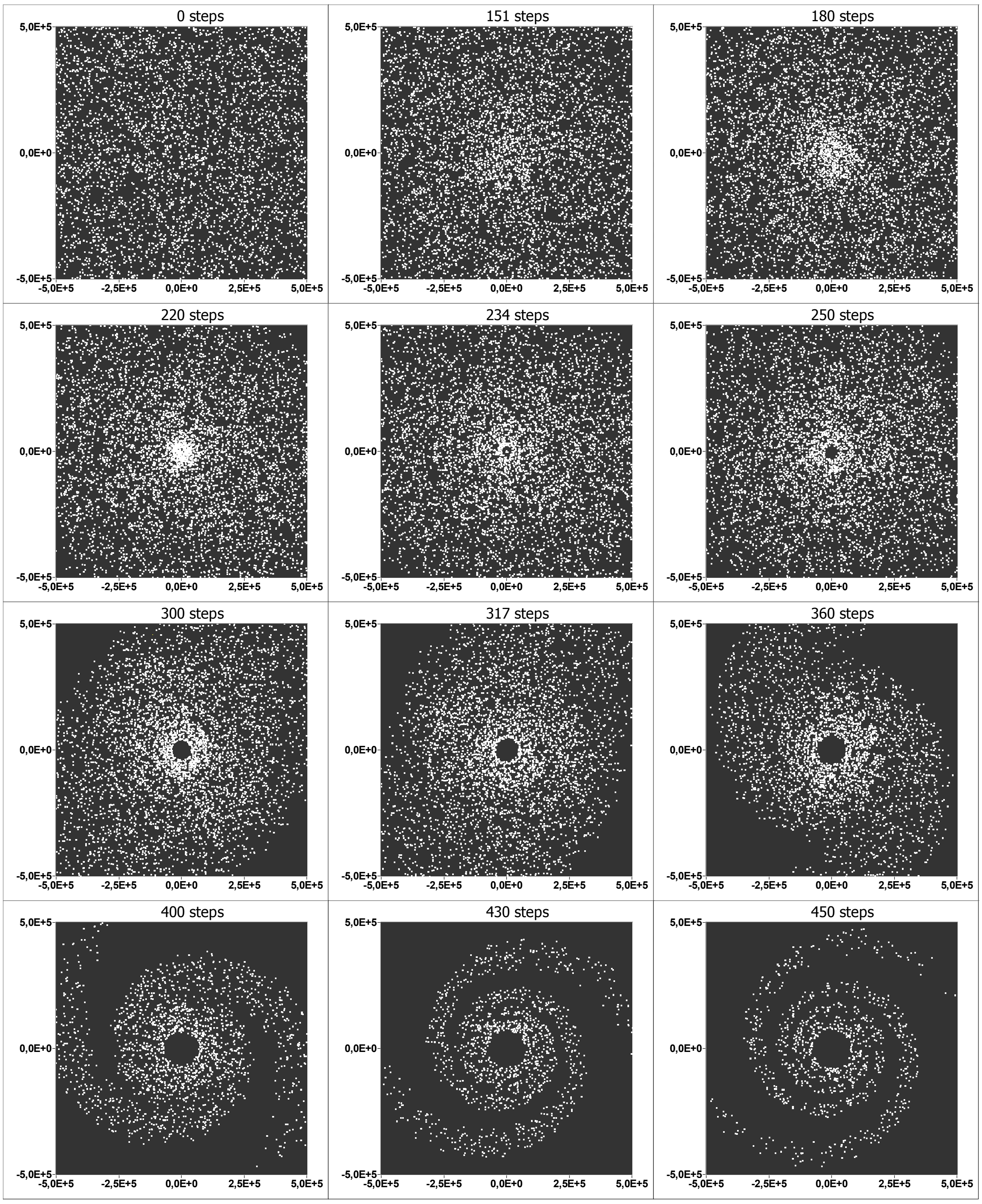

Fig. 2. The formation of the eye of the hurricane is shown in more detail. It starts to form in a middle stage of the process. Density near the eye's edge varies with time and periodic formation of the dense rings is observed as can be seen in the 317 steps graph.

Figure 3 shows the tangential and radial velocities of the cloud for different stages. At the beginning, the cloud rotates with angular velocity of $1x10^{-5}$ rad/s and the tangential velocities of the bodies form a linear-like radial dependency with a maximum speed of around 10 m/s at distances 1000 km from the center. This distance corresponds to double the radius of the final hurricane. During the contraction process, the linear dependency transforms dramatically. The bodies situated closer to the center start to rotate faster reaching typical extreme hurricane's velocities near the eye edge. The velocity dependency forms a smooth curve revealing that the process is a self-clocking in which every body contributes into the dynamics of the whole system. Inside the eye region, the density is very low and velocities are almost zero corresponding to calm weather and clean sky. These features are usually observed in the eye's regions of real hurricanes. The increase of the maximum velocity during the formation process correlates well with the extreme wind dependency proposed by Emmanuel (1999).

To simulate the contraction of the cloud in the presence of the surrounding atmosphere, we introduced a stationary external gravitational field by applying a repulsive force. The external field used in this simulation is symmetric about the axis of rotation. This associates with the homogeneous surrounding atmosphere. Figure 4 shows the result of the gravitational contraction of the same initial cloud as in Figure 1 but in different external gravitational fields. The intensity of the hurricane decreases with the increase of the external field. The less the difference between the environmental atmosphere and the cloud the slower-rotating and less intensive system is formed. The equalizing of the density of the cloud with the density of the surrounding atmosphere will result in no tropical cyclone.

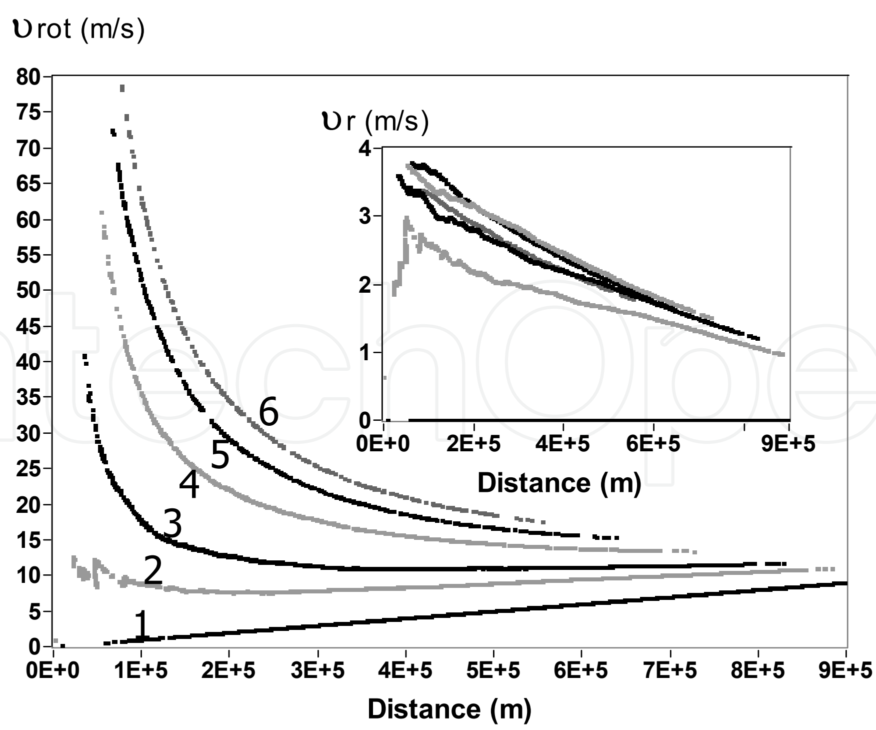

Fig. 3. Tangential v_{rot} and radial v_r velocities vs. distance from the centre of the cloud are shown for different stages of the formation of the hurricane.

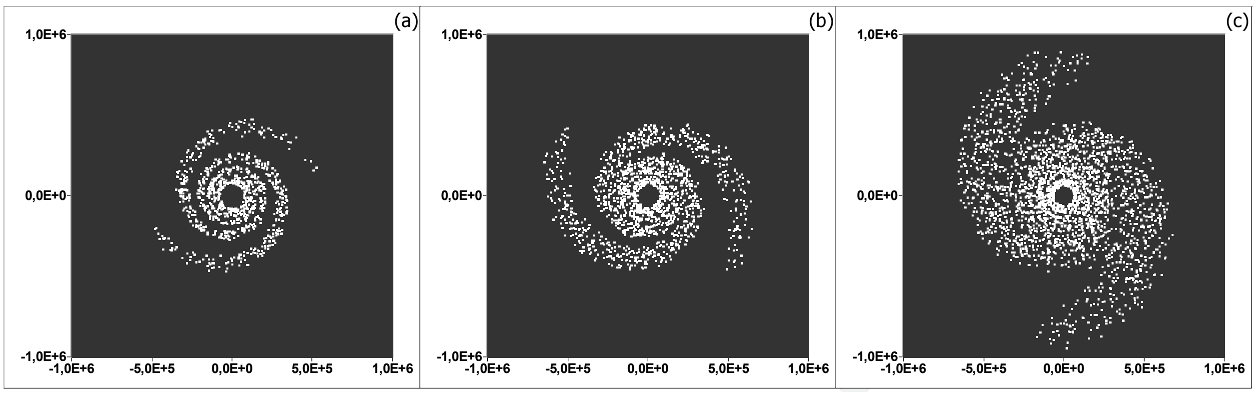

Fig. 4. The result of simulation of the same initial cloud as in Figure 1 but in the presence of surrounding gas of different density. The external gravitational field has central symmetry and is given by an effective density that is zero for graph (a), $2x10^{-2}$ kg m^{-3} (b) and $5x10^{-2}$ kg m^{-3} (c). All three hurricanes are shown after 450 steps of simulation. The graph (a) corresponds to the hurricane shown in Figure 1 (last graph). Apparently, the maximum velocities of the hurricane decrease with increase of the external density. The maximum velocity of the hurricane (a) is around 80 m/s whereas the maximum velocity of the hurricane (c) is 65 m/s. The diameter of the eye of the hurricane (c) decreased as well.

4. Discussion

In real conditions, the circulation process and surface winds produce a feedback mechanism when the loss of mass due to precipitations is compensated by upwards-rising water vapor flow along the eye wall in the middle of the hurricane. The difference between the falling-down mass and the rising mass leads to decreasing the intensity of the hurricane.

The disturbance of the balance in the atmosphere may result in more tropical storms. There are natural factors such as solar activity and local season weather that may influence the creation of the hurricanes. The variations of density are observed in other planets as well. A sharp density gradient (called the ionopause) in the atmosphere of Venus correlates with solar activity because this planet has no intrinsic magnetic field and therefore the solar wind interacts directly with ionosphere. Thus, magnetosphere of the Earth is the main natural obstacle for the hurricanes.

There is also a human factor that can be dominant in future global climate. The change of chemical composition of the atmosphere can distract its balance (Henderson-Sellers *et al*. 1998). For example, heavy elements, like CO_2, result of the industrial activity and disappearing the forests, may result in more frequent hurricanes (Knutson and Tulea 1999).

We can conclude that the gravitational model explains the origin of the hurricanes and can help to predict their formation at early stages. Our model uses minimum parameters making feasible the practical applications of the simulation program. The practical simulation can be performed based on initial data obtained from measuring the atmospheric gas density and wind velocity. The model for the hurricane can be generally applied for any tropical cyclone. Less dynamic tropical cyclones are characterized by less mass and smaller cloud's size and consequently weaker extreme winds.

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