## 3B. 2 PHENOMENOLOGICAL ANALYSIS OF FORCES IN HURRICANE DYNAMICS

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## 1. ABSTRACT

It is argued that electromagnetism effects may have significant or even dominant effects upon hurricane dynamics. Electromagnetic effects appear to be consistent with major hurricane characteristics, including most notably the eye. Elements of hurricane models are suggested. Simple experimental measurements are also suggested to evaluate the effects. If the hypothesis were to be found true, hurricane "management" techniques might be possible.

## 2. INTRODUCTION

Hurricanes seem to be difficult to predict, and can result in devastatingly harmful effects. To the nonmeteorologically trained, hurricane phenomena hold a great deal of mystery. In spite of obvious importance, this writer was unable to find literature rationale for whys and wherefores of hurricanes.

In particular, there seems to be much information regarding lightning resulting from highly electrically charged clouds. It is duly noted that lightning has a suspicious absence in large parts of hurricanes. Hurricanes/cyclones rotate in opposite directions in different hemispheres, and the earth magnetic field is opposite in the two hemispheres. During the most severe stages, Gulf of Mexico hurricanes tend to migrate dominantly northward in the earth magnetic direction field. They also trend westward at first then eastward as they reach more northerly latitudes. I found no compelling literature rationale for this almost universal behavior. Perhaps the earth magnetic field and the local iron content hold clues. If the hurricane forms a giant electromagnet, these behaviors would seem to be logical. ${ }^{*}$

Clouds are apparently highly electrically charged, as originally proven by that individual honored on our $\$ 100$ bill. As one accustomed to electrical solenoids in everyday use, and also seeing compass needles respond energetically to the

[^0]earth magnetic field, it is surprising to see (albeit after only internet searches) no reference to the interaction of fast moving, highly electrically charged clouds with the earth magnetic field. Hurricane Charley motivated this writer to a cursory examination of electromagnetic effects. Katrina and my wife Julie motivated this writing. Some hyperbole is evident in the discussions, but there would seem to be reason to experimentally and analytically pursue further thought along the lines suggested.

## 3. BUOYANCY FORCE

Vast Energy is present in hurricanes. The energy is derived largely from condensation of atmospheric water vapor, as is well known. Air moving over a warm water surface becomes saturated with water vapor. Table 1 compares dry air and air saturated with water vapor.

|  |  | Bone Dry | Bone Dry | Saturated | Saturated | Saturated | Saturated | Buoyant |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Temp | Temp | MWBar | Density | Pvap H2O | X H2O | MWBar | Density | Acceleration |
| Deg F | Deg C | gm/gmmol | gm/m3 | mmHg |  | $\mathrm{gm} / \mathrm{gmmol}$ | gm $/ \mathrm{m} 3$ | $\mathrm{~cm} / \mathrm{sec} / \mathrm{sec}$ |
| 60 | 15.6 | 28.6 | 1208 | 12.7 | 0.017 | 28.422 | 1200 | 6.12 |
| 70 | 21.1 | 28.6 | 1185 | 18.3 | 0.024 | 28.345 | 1174 | 8.81 |
| 80 | 26.7 | 28.6 | 1163 | 25.8 | 0.034 | 28.240 | 1148 | 12.49 |
| 90 | 32.2 | 28.6 | 1142 | 35.9 | 0.047 | 28.100 | 1122 | 17.45 |
| 100 | 37.8 | 28.6 | 1122 | 49.1 | 0.065 | 27.915 | 1095 | 24.05 |
| 110 | 43.3 | 28.6 | 1102 | 66.3 | 0.087 | 27.675 | 1066 | 32.76 |

TABLE 1. Saturated Air Properties
In Table 1 the rightmost column is the buoyant acceleration rate that saturated air would have if it were in a field of dry air and not subjected to energy dissipative effects such as turbulence. The acceleration is just the ratio of buoyant force to mass of air, a convenient way to quantify the force involved. The acceleration is a result of buoyant forces similar to a helium balloon. The buoyant forces are due to the lower average density of wet air compared to dry air. Dry air has an average molecular weight of about 28.6grams per gram mole. Since water has a molecular weight of only 18, mixing water into air reduces the average molecular weight, making the air less dense and hence buoyant compared to dry air.

Buoyancy of warm, moist air produces rising air columns, and hence can lead to low pressure zones. At higher altitudes water condensation heats the air and further promotes buoyancy. Air moves into the low pressure zones from
surrounding areas, and reduction of pressure promotes water condensation processes.

The buoyancy acceleration numbers provide a framework for comparison of Coriolis and dynamic electromagnetic effects. In practice, one would expect the buoyant force to be a moderate to large fraction of those numbers shown, since surrounding air would not be bone dry, but perhaps 50 to $80 \%$ relative humidity. If the relative humidity of surrounding air is, say $75 \%$, then the expected buoyant acceleration of a fully saturated ( $100 \%$ humidity) local mass of air would be $1 / 4^{\text {th }}$ that shown in the rightmost column above.

## 4. CORIOLIS EFFECTS

This paper first discusses Coriolis because it is the generally accepted mechanism for hurricane spin dynamics. The discussion is on a very basic level, and is presented as a backdrop and comparison standard for later discussion of electromagnetic effects.

Coriolis "forces" occur because of earth spin. At the equator, the earth surface is moving at approximately 1000 miles per hour, while at the poles it is not moving at all (relative to the position of earth in space). That is to say, at the equator the earth moves one entire earth circumference, 25,000 miles, in 24 hours). Since air is carried along with the earth surface, it is moving at similar velocities at the two locations. As air is convected from near equatorial locations toward the poles, the air would need to slow down to match the local earth surface velocity. Since there is no force to slow the air down, a rotational motion is induced. The phenomenon is characterized by the so-called Coriolis Effect. The vector equation relating this effect is:

$$
\begin{equation*}
\mathbf{F}_{\text {Coriolis }}=-2 m(\Omega \times \mathbf{v})=2 m(\mathbf{v} \times \Omega) \tag{1}
\end{equation*}
$$

To interpret this in terms of acceleration, simply take the ratio of force to mass as the acceleration and and obtain:

$$
\begin{equation*}
\mathbf{F}_{\text {Coriolis }} / \mathrm{m}=\mathrm{a}=2(\mathbf{v} \times \Omega) \tag{2}
\end{equation*}
$$

Where $\Omega$ is the earth vector angular velocity in radians per unit time, and $\mathbf{v}$ is the air velocity of interest. The $x$ in the above equation infers the vector cross product. The vector cross product magnitude can be obtained by multiplying the product of vector magnitudes by the angle sine function between the two vectors. The Earth angular velocity, $\Omega$ is one rotation per day, or $2 \pi$
radians per 24 hours; this being equal to $2 \pi /\left(24^{*} 3600\right)=0.000073$ radians per second. The inverse of this is 3.8 hours per radian. The angular velocity vector is parallel to the earth axis of rotation, and hence angled at the local latitude to the earth surface. Figure 1 illustrates the rotational vector and its resolution into component vectors tangential to the earth surface and radial from the center of earth. Note that the vertical component, given by $\Omega_{\mathrm{v}}=\Omega^{*} \sin ($ Latitude ) points toward the earth surface in the southern hemisphere and away from the earth surface in the northern hemisphere:


Earth rotational vector is along the axis through the poles. Relative to the earth surface, there is a vertical component of the rotational vector $\Omega \mathrm{v}$ toward space in the northern hemisphere, and toward earth in the southern hemisphere.
FIGURE 1. Coriolis Vector Vertical Components, Northern and Southern Hemispheres

The rotation vector component resolution is shown in a north south up down coordinate system in figure 2 :


Northern Hemisphere rotational vector components in a NSEWUD coordinate system

FIGURE 2. Rotation Vector Components

Since "Coriolis Force" is given by the cross product of air velocity and the rotational vector, force on air moving parallel to the local earth surface will only be induced by $\Omega_{v}=$ $\Omega^{*} \sin ($ Latitude ), the vertical component of rotation. And, that force will be perpendicular to both the air
velocity vector and the vertical component of rotation. The precise direction is given by the right hand rule, and is illustrated in the following diagrams


In the Northern Hemisphere, Where the Vertical Rotational Vector is Upward, Coriolis Force Pushes South Moving air to the West, a Right Hand Turning Effect.

FIGURE 3. Northern Hemisphere Coriolis Force on South Moving Air.


In the Northern Hemisphere, Where the Vertical Rotational Vector is Upward, Coriolis Force Pushes North Moving air to the East, a Right Hand Turning Effect.
FIGURE 4. Northern Hemisphere Coriolis Force on North Moving Air.


In the Northern Hemisphere, Where the Vertical Rotational Vector is Upward, Coriolis Force Pushes East Moving air to the South, a Right Hand Turning Effect.

FIGURE 5. Northern Hemisphere Coriolis Force on East Moving Air.

Figures 3-5 show that the right hand rule results in northern hemisphere air being forced into a right hand turn, regardless of what direction it is moving. This is the classically accepted reason for northern hemisphere air converging on a central low pressure region to rotate in a counterclockwise direction.


Viewed from space, air moving toward a low pressure center is Coriolis motivated in counter-clockwise manner by virtue of the Right hand turning effect

FIGURE 6. Northern Hemisphere Coriolis Forces induce Counter-Clockwise Motion.

Analogous reasoning for the southern hemisphere leads to clockwise rotation for air masses converging on a central low pressure region.

Similar reasoning shows that once air is rotating in a circular motion parallel to the earth surface, the Earth rotation vertical component leads to a radial force outward from the center as shown:


In-Plane Coriolis Force is Always Outward (Right Turn)

FIGURE 7. Northern Hemisphere Coriolis Force on Circular Air Motion is a Radially Outward Force.

The outward Coriolis force is in the same direction as centripetal force, and it is interesting that at large radii and lower velocities the centripetal force is actually smaller than the outward Coriolis Force. If centrifugal force per unit mass is ${ }^{2} r=V_{t}^{2} / r$, and the radially outward Coriolis force is $2 \mathrm{Vt} \Omega$ $\operatorname{Sin}$ (Latitude), then the ratio is given by $2(\mathrm{r} / \mathrm{Vt}) \Omega$ $\operatorname{Sin}($ Latitude ), where $r$ is the radius of circular air motion. Both the centrifugal force and the outward Coriolis force must be overcome by a radial pressure gradient sucking air in toward the rotational center.

Discussion thus far has centered upon interactions with the Earth vertical rotation vector component. The horizontal component $\Omega_{\mathrm{H}}=\Omega \operatorname{Cos}($ Latitude), also has effects, and they are most dramatic right at the equator. Realize of course that the vector direction of $\Omega_{\mathrm{H}}$ is north-south, so it will have no effect on air masses moving to the north or the south. However, $\Omega_{\mathrm{H}}$ definitely affects air masses moving to east or west. Right hand rule arguments similar to those invoked to produce Figures 2-6 show that at the southern edge of (a northern hemisphere) hurricane where air is moving west to east, the Coriolis force is upward. The effects at north and south edges of a hurricane are illustrated in figures 8 and 9 .


At Hurricane South Edge Coriolis Vertical Force is Upward
FIGURE 8. Effect of Earth Horizontal Rotation Component at South Edge of a Hurricane with Counter-Clockwise Motion is an Upward Force


At Hurricane North Edge Coriolis Force is Downward

FIGURE 9. Effect of Earth Horizontal Rotation Component at North Edge is a Downward Force.

Figure 10 shows the effect as air moves around a complete circle. The result if one tracks an air mass in a Lagrangian point of view is a sinusoidal vertical motion with the highest point occurring at the north-most edge and the lowest point at the south-most edge.


Hurricane is Forced to Lowest Point at South, Highest at North
FIGURE 10. Effect of Earth Horizontal Rotation Component on Circular Motion.

A more profound Coriolis Effect occurs on air rising or falling. Air with only vertical motion interacts only with the earth rotation horizontal component. The effect is to push vertically rising air masses to the west as shown in figure 11, and analogously, falling air masses will be pushed eastward. Since the most active rising air is near the hurricane center, one expects the hurricane eye to be motivated in a westerly direction.


FIGURE 11. Effect of Earth Horizontal Rotation Component on Rising Air.

The westerly velocity of rising air, in the absence of dissipative effects, can be estimated based upon analysis of Coriolis Effects. The relationship is

$$
\begin{align*}
\mathrm{F}_{\mathrm{w}} / \mathrm{m}=\mathrm{d} \mathrm{~V}_{\mathrm{w}} / \mathrm{dt}= & \mathrm{V}_{\mathrm{up}}{ }^{*} 2 \Omega_{\mathrm{H}}=\mathrm{V}_{\mathrm{up}} * 2 \Omega \operatorname{Cos}(\text { Latitude }) \\
& =\mathrm{dh} / \mathrm{dt} * 2 \Omega \operatorname{Cos}(\text { Latitude }) \tag{3}
\end{align*}
$$

Integrating from zero velocity at altitude $h_{1}$ to westerly velocity $\mathrm{V}_{\mathrm{w}}$ altitude at $\mathrm{h}_{2}$, gives the following result:

$$
\begin{equation*}
\mathrm{V}_{\mathrm{w}}=\Delta \mathrm{h} / \tau_{\mathrm{H}} \tag{4}
\end{equation*}
$$

Where $\Delta h=\left(h_{2}-h_{1}\right)$

$$
\tau_{\mathrm{H}}=1 /[2 \Omega \operatorname{Cos}(\text { Latitude })]
$$

$$
\approx 1 /\left[2^{*} 0.000073 \text { radian } / \mathrm{s}^{*} \operatorname{Cos}\left(20^{\circ}\right)\right]=2 \text { hours }
$$

So, at $\Delta h=10,000$ meters altitude, the result would be a rising column of air to be traveling westward at $5 \mathrm{~km} / \mathrm{hour}$. This is not a very significant velocity, and it would be even lower had dissipative terms been included in the analysis.

Turning to analysis of circular motion induced by Coriolis, consider air moving in toward a low pressure region. If an air pocket happens to be moving north along the earths surface at say 67.5 miles per hour ( 3000 centimeters per second) at a location with latitude $20^{\circ}$ above the equator, the Coriolis acceleration will be of magnitude:

$$
\begin{equation*}
\text { Coriolis Acceleration }=-2^{*} \Omega * \operatorname{Sin}\left(20^{\circ}\right)^{*} V_{r} \tag{5}
\end{equation*}
$$

$=-2^{*} .000073^{*} 3000 * 0.34=-0.15 \mathrm{~cm} / \mathrm{sec} / \mathrm{sec}$

This is approximately two orders of magnitude smaller than the buoyancy acceleration estimated in the first section. The vector math and physical mechanics shown earlier indicate that air pockets moving north and air pockets moving south will have Coriolis accelerations that cause right hand turns, leading to counter-clockwise air motion in the northern hemisphere and clockwise motion in the southern hemisphere. Curiously, Coriolis for movement parallel to the local earth surface is zero at the equator, and most dramatic near the poles due to the sine effect. This is curious because hurricanes tend to occur near the equator where Coriolis is weakest (but water is warmest); perhaps the competing effects maximize at just above the equatorial regions.

Presuming a radial velocity of $30 \mathrm{~m} / \mathrm{sec}$ for air heading toward a central low pressure region in a weather system with radius 100 km , the moving air will require $100,000 / 30$ or 3333 seconds to reach the innermost zones. During this time, the Coriolis acceleration will be $0.15 \mathrm{~cm} / \mathrm{sec}^{2}$, so to first order one might expect a tangential velocity near the center of $0.15^{*} 3333=498 \mathrm{~cm} / \mathrm{sec}=5 \mathrm{~m} / \mathrm{sec}$. This does not seem very high, but the analysis is first order.

A more explicit two-dimensional inviscid analysis to compute Coriolis effects is easily performed. Consider a simple model hurricane with incompressible air flow (nearly true), feeding into the hurricane from outer radii, and eventually disappearing at the very center via a magic mass sink (in reality the "sink" is the rising air due to heat and water condensation at the central region of a hurricane). The air feeds in at a rate of Q cubic meters per second. This simple hurricane has a height that can vary with radius by a function $h(r)$, that is a pancake in its simplest form, but could grow thicker or thinner with radius. The picture of this model, including a linear mass sink at the very centerline, is:


FIGURE 12. Circular Geometry for 2D Inviscid Hurricane Model

The radial velocity at any point is given by continuity:

$$
V_{r}=Q /\left[\begin{array}{ll}
2 & r h(r)]=d r / d t \tag{7}
\end{array}\right.
$$

It is of interest to compute the tangential velocity, $V_{t}$ that results from Coriolis effects interacting with the radial velocity, since this interaction produces the hurricane spin. The Coriolis imparts a tangential velocity component when it interacts with the radial velocity component. Again, at $20^{\circ}$ latitude, this is given by:

Coriolis Acceleration $=$ Force $_{\mathrm{t}} / \mathrm{m}=-2^{*} \Omega$ *

$$
\begin{equation*}
\operatorname{Sin}\left(20^{\circ}\right)^{*} V_{r}=d V_{t} / d t \tag{8}
\end{equation*}
$$

Solving equations (7) for dt and for $\mathrm{V}_{\mathrm{r}}$, and substituting into equation (8), and ignoring small latitude variation and the simple fact that Equation (8) is really a partial differential, (ignoring the partial differential characteristic results in a quasisteady state analysis) yields the result:

$$
\begin{equation*}
-2^{*} \Omega * \operatorname{Sin}\left(20^{\circ}\right)^{*} d r=d V_{t} \tag{9}
\end{equation*}
$$

The result is independent of $h(r)$; not surprisingly, given the Coriolis effect origin (local air velocity relative to earth center simply a function of latitude, so the induced velocity is simply dependent upon how far the air has moved from its original location).

In the case of circular motion, it is angular momentum that is conserved. Angular momentum, $L$, for a simple point mass is $L=. \mathrm{m} \mathrm{r}^{2}$ $=m r \quad r=m r V_{t}$, where $r$ is the radial distance from the center of rotation, is the angular velocity about the center of rotation, and $m$ is the object mass (in this case of interest, consider a single kilogram of air, about one cubic meter). Angular momentum is conserved unless a torque is exerted on the system. So,

$$
\begin{gather*}
\mathrm{L} / \mathrm{m}=\mathrm{r} \mathrm{~V}_{\mathrm{t}} \mathrm{~d}(\mathrm{~L} / \mathrm{m}) / \mathrm{dt}=\mathrm{d}\left(\mathrm{r} \mathrm{~V}_{\mathrm{t}}\right) / \mathrm{dt}=\text { Torque } \\
=\text { Force }_{t}^{*} \mathrm{r} \tag{10}
\end{gather*}
$$

Ignoring for the moment any torque other than the Coriolis force torque and substituting equation (8) into equation (10), a formula results that can be used to compute the angular momentum of the kilogram of moist air:

$$
\begin{align*}
\mathrm{d}(\mathrm{~L} / \mathrm{m})=\mathrm{d}\left(\mathrm{r} \mathrm{~V}_{\mathrm{t}}\right)={\text { Force } e_{\mathrm{t}} r^{*} \mathrm{dt}} \\
=\left[-2^{*} \Omega^{*} \mathrm{~V}_{\mathrm{r}}{ }^{*} \operatorname{Sin}\left(20^{\circ}\right)\right]^{*} \mathrm{r}^{*}\left(\mathrm{dr} / \mathrm{V}_{\mathrm{r}}\right) \tag{11}
\end{align*}
$$

Ignoring variation of latitude with radius, and integrating equation (11) over limits from some outer radius $r_{\text {max }}$ where the tangential velocity is near zero ( $\mathrm{L} / \mathrm{m}=0$ ), to an arbitrary inner radius $r$ where it is interesting to know the Coriolis induced tangential velocity component. The result is:

$$
\begin{align*}
& L / m=r V_{t}=\Omega^{*} \operatorname{Sin}\left(20^{\circ}\right)^{*}\left(r_{\max }^{2}-r^{2}\right)  \tag{12}\\
& V_{t}=\Omega^{*} \operatorname{Sin}\left(20^{\circ}\right)^{*}\left(r_{\max }^{2}-r^{2}\right) / r  \tag{13}\\
& V_{t}=\Omega^{*} \operatorname{Sin}\left(20^{\circ}\right)^{*}\left(r_{\max }-r\right)\left(r_{\max }+r\right) / r  \tag{14}\\
& V_{t}=\left(1+r_{\max } / r\right)\left(r_{\max }-r\right) / \tau \tag{15}
\end{align*}
$$

Where $\tau$ is a characteristic Coriolis time equal to $1 /\left[\Omega\right.$ * $\operatorname{Sin}$ (Latitude) ]. At $20^{\circ}$ latitude, $\tau=11.2$ hours. At about $18.5^{\circ}$ latitude, $\tau=12$ hours, a number easy to use for simple calculations. (Note that $\tau$ becomes a shorter time period at more northern latitudes.) If the tangential velocity is negligible at a radius of say 300 km ( 180 miles), then the largest tangential velocity one can expect from Coriolis effects would occur near the center. Assuming an eye at say about 20km radius, equation (13) computes a tangential velocity of $(1+15)^{*}(300-20) / 12=373 \mathrm{~km} / \mathrm{hr}=224 \mathrm{mph}$. This certainly is not an insignificant wind velocity. It is similar to velocities observed in real-world hurricanes. The result is somewhat extreme because no account was taken of any dissipative effects. The most important dissipative effect would be reverse torque exerted on the hurricane structure by interaction with the earth surface and with upper and lower atmosphere having no tangential motion. Of course, the radial and tangential velocities need to be vectorially added, but the most violent portions of hurricanes seem to be primarily tangential velocity.

The relationship equation (15) should also be valid for the classic water down the drain example. In this situation, an outer radius of 100 centimeters, and an inner radius of say 2 centimeters would yield a tangential velocity of $(1+50)^{*}(100-2) / 3=$ $1666 \mathrm{~cm} /$ hour or $0.5 \mathrm{~cm} / \mathrm{sec}$. The argument often is that very small initial tangential velocity at the periphery of such an experiment would probably overwhelm this small velocity. A clockwise peripheral velocity of $0.01 \mathrm{~cm} / \mathrm{sec}(0.6 \mathrm{~cm} /$ minute $)$ would do exactly that, based on the conservation of momentum.

The cross-product relationship for Coriolis force indicates force perpendicular to the gas velocity
vector. Here, it has been assumed that the radial velocity persists even as it is being converted to tangential velocity. This assumption is consistent if there is a radial pressure gradient that maintains radial velocity even as some kinetic energy is transformed to tangential motion. Thus, it is maintenance of radial inflow caused by rising air at the hurricane center that provides the energy for this very violent phenomenon. Pressure gradients and tangential velocities usually are more extreme near the center of hurricane weather systems, and they are nominally symmetric about the hurricane center. The tangential velocity component leads to a radial pressure gradient.

Equation (15) gives the circular velocity in a hurricane. Equation (15) is the largest value one might expect since dissipative effects were not included. Because there is circular motion, centrifugal force effects tend to keep air masses from moving in toward the hurricane weather system center. As noted earlier in Figure 7, Coriolis also exerts a radial outward impetus to the circular flow. Together, the two centrifugal forces must be offset by a centripetal force. The centripetal force takes the form of a radial pressure gradient, with lower pressure in the central regions. A straightforward analysis, without dissipative effects, can be used to estimate the required pressure gradients. Having an estimate of tangential velocity in a hurricane further allows an estimate of radial pressure gradient. If the hurricane weather system is to maintain a radial inflow of air, the inflow must overcome Coriolis and Centripetal forces. Both these forces are in the radially outward direction. These forces must be overcome by a radial pressure gradient with lower pressures near the hurricane center. This is expressed algebraically by the following expression:

$$
\begin{align*}
\rho \mathrm{dP} / \mathrm{dr} & =\mathrm{F}_{\text {centrifugal }} / \mathrm{m}+\mathrm{F}_{\text {Coriolis }} / \mathrm{m} \\
& =\mathrm{V}_{\mathrm{t}}^{2} / \mathrm{r}+2 \mathrm{~V}_{\mathrm{t}}^{*} \Omega * \operatorname{Sin}(\text { Latitude })  \tag{16a}\\
& =\mathrm{V}_{\mathrm{t}}^{2} / r+2 \mathrm{~V}_{\mathrm{t}} / \tau \tag{16b}
\end{align*}
$$

Where air density is $\rho$, assumed invariant, and the Bernoulli effect of increasing radial velocity approaching the center has been at least temporarily ignored Using Equation 15, and integrating from $r_{\text {max }}$ to $r$, the following result is obtained:

$$
\begin{align*}
\Delta P & =\left[r_{\max }^{2}-r_{\max }^{4} / 2 r^{2}-r^{2} / 2\right] /\left[\rho . \tau^{2}\right] \\
& =P_{@ r}-P_{@ r \max } \tag{17}
\end{align*}
$$

This relationship clearly extrapolates to negative infinity at zero radius, reminiscent of tornadoes, but not seen in hurricanes.

Figure 13 shows results for pressure and velocity as a function of radius for selected conditions at $r_{\text {max }}$. Recall that these are the most extreme conditions, at $20^{\circ}$ latitude, since no damping forces have been included in the analysis. Certainly the values are consistent with the concept of maximum observed effects, as noted by the included extreme pressure gradients observed in prior hurricanes.


FIGURE 13. Computed Pressure and Tangential Velocity for Un-damped Hurricanes at $20^{\circ}$ Latitude.

Figure 13 applies to the noted latitude, with the previously mentioned simplification of no significant latitude variation with radius. For other latitudes, the velocity profile varies significantly as noted in Figure 14:


Figure 14. Velocity Profiles at Various Latitudes.
From continuity, the radial velocity of a two dimensional hurricane can be expressed as $\mathrm{V}_{\mathrm{r}}=\mathrm{V}_{\mathrm{ri}}{ }^{*} r_{\text {max }} / r$, Where $\mathrm{V}_{\mathrm{ri}}$ is the radial velocity at $r=r_{\text {max }}$, the location where zero tangential velocity was assumed. With this very simplified relationship, transit time from $r_{\max }$ to $r$ is time $=$ $\left(r_{\max }{ }^{2}-r{ }^{2}\right) /\left(2 V_{\text {ri }} r_{\text {max }}\right)$. If is assumed that $r_{\max }=300 \mathrm{~km}, \quad \mathrm{r}=20 \mathrm{~km}$ (the eye?), and $\mathrm{V}_{\mathrm{ri}}=$ $0.5 \mathrm{~m} / \mathrm{sec}$, then transit time from the outer radius to the eye would be slightly in excess of three full days, and radial velocity at the eye would be $7.5 \mathrm{~m} / \mathrm{sec}(27 \mathrm{~km} / \mathrm{hr}$ about 17 mph ). This number seems a bit low, but ignoring that, these numbers and the computed tangential velocity allow a computed estimate of the total power of this two dimensional hurricane, if hurricane thickness is known. Assuming a 2 km thick two dimensional hurricane, the volumetric flow of air into the hurricane is $2 \pi r_{\max } \mathrm{h} \mathrm{V}_{\mathrm{ri}}=\mathrm{Q}=2$ billion cubic meters per second. The tangential velocity previously estimated was $373 \mathrm{~km} / \mathrm{hr}$, and when vectorially combined with a $27 \mathrm{~km} / \mathrm{hr}$ radial velocity, the total velocity is about $373.8 \mathrm{~km} / \mathrm{hr}$ or $104 \mathrm{~m} / \mathrm{sec}$. Assuming the air motivated to this velocity disappears into a hypothetical mass sink, the power to maintain this hurricane is $0.5^{*} \mathrm{Q}^{*} \rho \mathrm{~V}^{2}$. This number works out to about 16 billion horsepower, or the heat of condensation of 6 thousand tons of water per second. This quantity of water taken from an area the size of a 20 km radius eye would vaporize about 7 cm depth of water in one hour; however, over the total area of the assumed 300 km outer radius hurricane, the vaporization would be only about one half cm per hour. These numbers are all directly proportional to the assumed radial velocity at $r_{\text {max }}$. The very high horsepower noted is equivalent to about the
horsepower generated by every automobile in the USA operating at full throttle. It is no wonder that hurricanes can do so very much damage. This energy is for a large part derived from the earth rotational energy. It would be an interesting exercise to calculate how much the earth's rotation rate is slowed by a large and enduring hurricane.

Real hurricanes are less extreme than the undamped hurricane represented by Figure 13. Real hurricanes are damped by drag forces. Drag forces on air at higher and lower elevations have effects, but momentum transferred to those layers should probably just be considered part of the hurricane. Drag on physical objects such as trees, waves, houses, etc., located on the earth surface is a real dissipative effect on the hurricane. Consider a physical object with cross-sectional area $A$ and drag coefficient $C_{d}$, exposed to a unit volume of air of velocity $\mathrm{V}_{\mathrm{t}}$ and air density $\rho$. The drag force per unit volume of air is given by Force ${ }_{d} /$ mass $=\mathrm{C}_{\mathrm{d}}{\mathrm{A} \rho \mathrm{V}_{\mathrm{t}}{ }^{2} / 2 \rho \text {. Recall that, as taken, } \mathrm{A}}^{\text {. }}$ is area per unit volume $\left(\mathrm{m}^{2} / \mathrm{m} 3\right.$ or $\left.\mathrm{m}^{-1}\right)$. If the drag occurs at a radius $r$ from the hurricane center, the drag force causes an adverse torque on the hurricane air mass system given by Force ${ }_{d}{ }^{*} r$. This torque is termed "adverse", since it is in opposite direction to the nominal tangential direction of motion. If the drag areas under consideration are assumed to be distributed uniformly throughout the hurricane system, a small area can be attributed to the kilogram of air considered previously in equation (11), and then (11) can be rewritten as:

$$
\begin{gather*}
d\left(r V_{t}\right)=\left(\text { Force }_{c}-\text { Force }_{d}\right)^{*} r^{*} d t=-2^{*} \Omega{ }^{*} \operatorname{Sin}\left(20^{\circ}\right)^{*} \\
r^{*} V_{r} d t+r \operatorname{CdA\rho } V_{t}^{2} / 2 d t \tag{18}
\end{gather*}
$$

Where, the last collection of terms on the right is the torque due to drag by the distributed area exposed to the kilogram of air, and the first collection of terms is the torque due to Coriolis Effects. Using the simple expression $\mathrm{dr}=\mathrm{V}_{\mathrm{r}} \mathrm{dt}$, and collecting terms:

$$
\begin{align*}
& \mathrm{d}\left(\mathrm{r} \mathrm{~V}_{\mathrm{t}}\right)= \\
& \left.\quad-2^{*} \Omega^{*} \operatorname{Sin}\left(20^{\circ}\right)^{*} r d r+C d A \rho V_{r} V_{t} / V_{r}\right)^{2} r d r / 2 \tag{19}
\end{align*}
$$

If Equation (19) is integrated from some outer maximum radius (say $300,000 \mathrm{~m}$ ), starting with a small radial velocity (say $0.5 \mathrm{~m} / \mathrm{sec}$ ), then the results at $20^{\circ}$ latitude are given in the following chart( drag coefficient assumed to be unity):


Figure 15. Velocity Profiles at $20^{\circ}$ Latitude with Various Drag Areas ( $\mathrm{m}^{2} / \mathrm{m}^{3}$ ).

The areas used as parameters in Figure (15) are relatively small. For the value of $10^{-6}$ square meters per cubic meter, the area is equivalent to a single wire one micron in diameter stretched across each cubic meter of air. However, most damping occurs when the high velocity winds interact with objects on the ground. If the only obstructions were objects 5 meters tall, and the total hurricane was 20 km high, then (based on simplistic rationale) the obstructions might be about $20,000 / 5$ or 4,000 times as wide, amounting to about 4 millimeter wires 5 meters tall. If the hurricane is to be extremely damped, it would take objects equivalent to the bottom-most curve, or about 40 millmeters wide by 5 meters tall, with good and effective momentum transfer through hurricane horizontal layers. Of course, this simple rationale does not take into account that air velocities should be much reduced at ground level, so it might be expected that much larger obstructions are required for significant damping. These estimates again are dependent upon the assumed radial velocity here taken as $5 \mathrm{~m} / \mathrm{s}$, but possibly an order of magnitude larger.

## 6. ELECTROMAGNETIC EFFECTS

The following quote is taken from NASA's Tropical Rainfall Measuring Mission (TRMM) as given in http://www.gsfc.nasa.gov/gsfc/service/gallery/fact sheets/earthsci/trmm/anatomy.html :
"One of the distinctive side effects of a thunderstorm is lightning, which has played a dominant role in mythology, and is responsible for the deaths of hundreds of people and millions of
dollars in property damage each year. Without lightning, there would be no thunder.

At its simplest level, lightning is caused by the build up of an electrical charge in large, vertical forming clouds. Initially, a cloud builds up an electrical charge of approximately 300,000 volts per foot ( 1 million volts per meter) by the rise and fall of air currents."

The origin of electrical charge on water particles (droplets or ice/snow) is not entirely clear, but its presence is well known. There is a large electrical potential gradient from the earth's surface to the atmosphere edge, caused in part by interaction of solar rays/particles with the atmosphere. The electrical gradient in the atmosphere appears to be intimately involved in electrical charges on water particles. The presence of net negative electrical charge in atmospheric water particles is dramatically demonstrated when (lightning) discharges occur. These discharges involve electrons transmitted to earth or between clouds. Clearly, the electrical charges are strong enough to lead to electrical air breakdown.

As air rises due to buoyancy effects noted earlier, it expands due to the decreasing pressure at higher altitudes. This expansion effect causes air cooling due to PV (Pressure-Volume) work the air performs as air expands, known as an adiabatic expansion. Cooler air at high altitudes is well known to pilots who experience temperatures of about $-70 \mathrm{~F}(-57 \mathrm{C})$ at typical $35,000 \mathrm{ft}$ altitudes. As the air rises and reaches reduced pressure, the vapor partial pressure of water contained in the air reduces by a similar fraction. However, with the corresponding decreased temperature due to adiabatic expansion, the equilibrium vapor pressure of water decreases proportionately more rapidly than the partial pressure of water vapor. Depending upon altitude and temperature, water condenses as either liquid water or solid water (ice, snow). Precipitated water is the material of clouds typically seen at altitude. The result is that water is condensed as air rises. Interestingly, the latent heat of water condensation causes the air to warm by an amount that tends to offset water vapor precipitation. For example, air saturated at 90 F is warmed by 75C (135F) just due to water vapor transitioning to ice/snow. This is a tremendous energy, and it accelerates the buoyant rise of water laden air as condensation begins. The condensation effect is clouded by the possibility of supersaturation. Supersaturation
phenomena are well known in supersonic aerodynamics, wherein water typically does not condense until temperatures 33C (60F) below the saturation point. This writer happens to be intimately acquainted with water vapor condensation when moist gases are flowed through supersonic nozzles. So called condensation shock waves occur when nucleation processes lead to abrupt water condensation in supersonic nozzles. Electrical charging of droplets formed in supersonic nozzles also occurs, sometimes resulting in spectacular electrical discharges in supersonic moist flow nozzles.

Consider one cubic meter of air saturated at 90 F with water vapor. According to Table 1, the vapor pressure of saturated water at 32C (90F) is 35.9 mmHg . The partial density of water vapor at 35.9 mmHg is approximately 34 grams of water per cubic meter of air (about $1 / 10^{\text {th }}$ cup of coffee in liquid form). To assess the possibility that electromagnetic forces have a role to play in hurricane dynamics, conjecture that the charge on clouds is characteristic of near electrical breakdown. Clouds often experience lightning phenomena, inferring very high electrical charges. Paint spray technology uses electrostatics to achieve high level droplet charge effects without electrical breakdown of air. Commercial atomizing devices, reference 1, (Measuring Charge-To-Mass Ratio Of Individual Droplets Using Phase Doppler Interferometery T. Gemci, R. Hitron and N. Chigier) (Chigier@andrew.cmu.edu www.andrew.cmu.edu/user/tgemci/ ILASS2002-Americas-Electrospray.pdf ) can obtain charge ratios of up to 5000 mC per kg (milli-Coulombs per kilogram) of water. In a cubic meter of 90F saturated air with about $34 \mathrm{gms}(0.034 \mathrm{~kg})$ of water charged to the $5000 \mathrm{mC} / \mathrm{kg}$ value, the cubic meter would contain $170 \mathrm{mC}=0.170$ Coulombs of charge. Clouds, like fog, are typically very small particles, under 10 microns diameter. Commercial paint atomizers operate in close proximity to electrically grounded targets without discharge, and droplets are typically near 10 microns in diameter. High altitude clouds can have sub-micron particle diameter and often discharge 1000 meters to the ground. Thus, clouds may have a much larger electrical charge. For estimation purposes recognizing that the charge level could easily be more for the small fog particles, postulate 1.7 coulombs per cubic meter, ten times that observed in paint spray devices

Like the electric field, the magnetic field can be defined by the force it produces:

$$
\begin{equation*}
\mathbf{F}=q \mathbf{v} \times \mathbf{B} \tag{20}
\end{equation*}
$$

Where, in SI Units:

> F is the vector force, Newtons X indicates a vector cross product q is electric charge, Coulombs (+ or - )
> V is electric charge vector velocity, measured in meters per second B is magnetic flux density vector, Teslas (Newton-sec/Coulomb-meter)

The magnetic flux density vector points northwesterly $\left(6.5^{\circ}\right)$ and downward $\left(60^{\circ}\right)$ in the northern hemisphere near the Gulf of Mexico. The electrical charge of concerned is negative, so a negative value of $q$ is required in equation (20). For Negative Charges, equation (18) can be rewritten:

$$
\begin{equation*}
F /(-q)=-v \times B=B \times v \tag{21}
\end{equation*}
$$

Using the vector cross product right hand rule for south-moving negatively charged air, gives the following result:


In the Northern Hemisphere, Where the Vertical Earth Magnetic Vector is Downward, B x V Force Pushes South Moving air to the West, a Right Hand Turning Effect.
Figure 16. Right-Hand Turn due to Moving Charge in the Northern Hemisphere Earth magnetic Field.

Figure 16 shows that the ambient northern hemisphere earth magnetic field tends to turn negatively charged moving air masses to the right, just as found with the Coriolis Effect. Figure 16 is directly analogous to the previous Figure 3 illustration of Coriolis for south moving air. Similarly, results analogous to Figures 4, 5, 6, and 7 are easily shown, indicating a counter-clockwise motion is induced in the northern hemisphere by action of earth magnetic field on negatively charged moving clouds, and an outward force on the rotating flow-field is applied by magnetic field effects.. Also, since the vertical magnetic field
changes direction in the Southern Hemisphere (except near the equator), the opposite is true in the southern hemisphere, leading to clockwise motion in that hemisphere. In fact, if the earth were not rotating at all, completely eliminating Coriolis, it would not be surprising to see hurricane rotational characteristics much as they are currently observed.

The equivalent to figure 7 for electromagnetic effects is shown in below in figure 17:


In-Plane Electromagnetic Force is Always Outward (Right Turn)
Figure 17. Centripetal Force Generated by Interaction of Tangential Velocity of Negatively Charged Clouds and the Magnetic Field.

The story is similar for vertically rising negatively charged air responding to $\mathbf{B x V}$ effects in the northern hemisphere, except the slight difference in B field northerly direction leads to a East North Easterly direction:


Vertically Rising Negatively Charged Air is Forced ENE by Earth Magnetic Field Effects
Figure 18. NNW Turn due to Vertically Rising Charge in Northern Hemisphere Earth magnetic Field

This effect is in opposite direction compared to the effect observed for Coriolis. Note that in the Gulf of Mexico region, the horizontal magnetic field
component magnitude is only about half the vertical magnitude. This is in stark contrast to the Gulf region Coriolis vector magnitude for which the horizontal component is 2 to 3 times the vertical component.

Similarly, up-down forces can be evaluated at hurricane north and south edges. This is shown at the south edge in the following figure:


At Hurricane South Edge Electromagnetic Force on Moving Negatively Charged Air is Downward
Figure 19. At Hurricane South Edge, Rotating Charge in Northern Hemisphere Earth magnetic Field is Forced Down, Opposite from the Coriolis Effect.

It is noted that the direction is opposite that to the Coriolis effect. A similar evaluation at the North edge shows an opposite effect compared to Coriolis. Strictly speaking, the evaluation relates to magnetic north (the south pole of earth taken as a magnet), not terrestrial north.

The National Geophysical Data Center provides a calculator to estimate the components of earth's magnetic field (http://www.ngdc.noaa.gov/seg/geomag/jsp/IGRF.j sp ) For Latitude 30, Longitude 80, in the northern hemisphere gulf region, the vertical component value is $41,500 \mathrm{nT}$ (nano-Tesla) or $41,500 \times 10^{-9}$ Teslas. Here th interest is mainly in the vertical component because it leads to counterclockwise rotation of charged air masses converging radially along the earth surface into a central location. From the above equation, and noting that the angle is 90 degrees (Sine=1.00) between air moving parallel to the local earth surface and the vertical magnetic field, one can calculate the rotational force on a cubic meter of air with an assumed 1.7 coulomb electrical charge and a 30 $\mathrm{m} / \mathrm{sec}$ velocity. The magnitude is:
$F=-1.77 \times 30 \times 41500 \times 10^{-9}=-0.0021$ Newtons

Starting with one cubic meter of air at sea level, it expands as it rises, but its mass remains the same. Since a cubic meter of sea level air weighs about 1.2 kg , the result infers an acceleration rate of $0.0017 \mathrm{~m} / \mathrm{s} / \mathrm{s}$, or $0.18 \mathrm{~cm} / \mathrm{s} / \mathrm{s}$. This is almost 4 times the $0.05 \mathrm{~cm} / \mathrm{sec} / \mathrm{sec}$ acceleration due to Coriolis, and therefore at this charge level, electromagnetic forces must be regarded as very significant compared to Coriolis in hurricane dynamics. At charge levels an order of magnitude smaller, electromagnetic forces would be significant, but not dominant. Here again, as discussed relative to Coriolis effects, the crossproduct results in right hand turn tangential velocity, and there must be a radial pressure gradient if radial velocity is to be maintained.

Coriolis Effect analyses presented earlier to produce equations 15 and 17 for tangential velocity and radial pressure gradients are equally valid for electromagnetic effects, for use of an appropriate characteristic time constant $(\tau)$ value. For Coriolis, $\tau$ is simply equal to the horizontal component rotational vector reciprocal, $1 /[\Omega$ * $\operatorname{Sin}$ (Latitude) ], and it has a magnitude of approximately 11.2 hours at $20^{\circ}$ latitude. For electromagnetic effects, the appropriate form for $\tau$ is easily shown to be

$$
\begin{equation*}
\tau_{\mathrm{E}}=2 /\left[\mathrm{B}_{\mathrm{v}}(\mathrm{q} / \mathrm{m})\right] \tag{23}
\end{equation*}
$$

Where, the quantity ( $q / m$ ) is the electrical charge per unit mass of air. Earlier the charge was assumed to be $1.7 \mathrm{C} / \mathrm{m}^{3}$, corresponding to approximately 1.4 Coulombs per kilogram of air. In this case, the time constant would be:

$$
\begin{align*}
\tau_{E}= & 2 /\left[\mathrm{B}_{\mathrm{v}}(\mathrm{q} / \mathrm{m})\right]=2 /\left(41500 * 10^{-9} * 1.4\right) \\
& =34,400 \mathrm{sec}=9.6 \text { hours } \tag{24}
\end{align*}
$$

Using the characteristic electromagnetic time constant, $\tau_{\mathrm{E}}$, previous relations given in equations (15) and (17) for Coriolis become:

$$
\begin{align*}
V_{t} & =\left(1+r_{\max } / r\right)\left(r_{\max }-r\right) / \tau_{E}  \tag{25}\\
\Delta P & =\left[r_{\max }^{2}-r_{\max }^{4} / 2 r^{2}-r^{2} / 2\right] /\left[\rho \tau_{E}^{2}\right] \\
& =P_{@ r}-P_{@ r \max } \tag{26}
\end{align*}
$$

Which are identical except for the time constant value being (for this example) a factor of 11.2/9.6 $=1.15$ times smaller. This would lead to tangential
velocities $1.15 x$ those previously calculated, and pressure gradients $1.15^{2}=1.3$ times larger. Clearly, the charge level postulated can be relaxed and still cause effects identical in magnitude to Coriolis.

Equation (26) ignores Coriolis effects. It is the point of this paper to introduce the possible significance of electromagnetic effects relative to hurricanes. Equation (26) would only be applicable if the earth were not rotating. Since it is certain the earth is in fact rotating, the effects of Coriolis and electromagnetism must be taken into account together. Taking both effects together, equation (11) becomes:

$$
\begin{align*}
& d\left(r V_{t}\right)=\text { Force }_{t}^{*} r^{*} d t \\
& =\left\{\left[-2 \Omega V_{r} \operatorname{Sin}\left(20^{\circ}\right)\right]+\left[B_{v}(q / m) V_{r}\right]\right\} r\left(d r / V_{r}\right)  \tag{27}\\
& o r, \\
& d\left(r V_{t}\right)=2\left[1 / \tau+1 / \tau_{E}\right] V_{r} r\left(d r / V_{r}\right) \\
& \quad=2\left[1 / \tau_{M}\right] V_{r} r\left(d r / V_{r}\right) \tag{28}
\end{align*}
$$

Which defines a composite time constant $\tau_{\mathrm{M}}=\tau^{*} \tau_{\mathrm{E}} /\left(\tau+\tau_{\mathrm{E}}\right)$. If the respective Coriolis and Electromagnetic time constants are 9.6 and 11.2 hours, the composite time constant is $\tau_{\mathrm{M}}=5.17$ hours. If both effects are present, $\tau_{\mathrm{M}}$ can be substituted for $\tau$ in equations $(15-17)$ to get the net result of both effects.

The foregoing has by no means proven the significance of electromagnetic effects in hurricanes; but, the possibility of electromagnetic effects cannot be easily dismissed. This possibility is even more intriguing in light of minimal lightning in hurricane clouds, and later discussion showing that electromagnetic effects may be selfbootstrapping to perhaps two orders of magnitude greater than expected from the ambient earth magnetic field.

A relevant question is whether or not electromagnetic effects are consistent with hurricane characteristics. Certainly the most dramatic characteristic of hurricanes is the universal counter-clockwise motion in the northern hemisphere and the analogous clockwise motion (of cyclones) in the southern hemisphere. This characteristic is generally attributed to the nature of Coriolis effects, and was easily shown in the previous section to be consistent with the tilt angle
between the earth rotational axis and the local earth surface. However, it has been shown above that identically similar effects occur with the electromagnetism related to the earth magnetic field. Always bear in mind that the earth currently has the south magnetic pole located near the north geographic pole (making it very easy to get the sign wrong when considering electromagnetic effects in hurricanes). In the northern hemisphere the Earth magnetic field vertical component is in the direction from sky to Earth. The Earth magnetic field is a very transitory phenomenon, and it has been shown to reverse polarity in the past. Just as changing climate can affect hurricanes, the changing magnetic field may also affect hurricanes. Currently, the location of Magnetic North is moving toward Alaska, and as it moves, the vertical component near the Gulf of Mexico equatorial region is increasing.

In the southern hemisphere (except near the equator), the magnetic field is opposite in direction to the northern hemisphere magnetic field, being oriented vertically from earth to sky. This causes the opposite rotational effect in the southern hemisphere, exactly as observed in hurricanes/cyclones.

The earth magnetic field vertical component magnitude is shown in figure 20, using data taken from the above mentioned NGDC source. The data shown are for the Gulf Region. In Figure 20, it is noted that the vertical component of magnetic field becomes stronger moving northward away from the equatorial regions, analogous to the Coriolis Effect. However, the Gulf Region vertical magnetic field component has a zero cross-over south of the equator leading to higher fields at low latitudes. Right at the equator, it is possible to have hurricane effects induced solely by electromagnetic effects, since there are no net Coriolis effects at the equator. If electromagnetism plays a significant role, one would expect less dramatic southern hemisphere hurricanes (typhoons) due to the lower field component in the warm water regions.


FIGURE 20. Earth Magnetic Field, Vertical Component, Gulf of Mexico.

The magnetic field crossover is not identically at the equator. Since water is generally warm at the equatorial region there is high water vapor pressure and hence high probability of storms of interest in the equatorial regions. However, even in the Gulf Region, the magnetic field vertical component is small until latitudes near the gulf coast where warm water is still present. Hurricanes tend to become more violent as they move northward (toward regions of higher earth vertical magnetic field components, and higher earth vertical rotational vector component.) The increased hurricane violence at more northerly latitudes was illustrated in figures 13 and 14 for Coriolis effects, and the exactly analogous effect can be shown for electromagnetically driven hurricanes.

Clouds are well known to be reservoirs of electrical charge. If hurricane clouds are significantly electrically charged, then one would expect the rotating clouds to act identically as a large electrical solenoid. The solenoid is formed by electrically charged clouds rotating about the central low pressure zone. The atmospheric solenoid of interest is flat like a pancake rather than the long narrow solenoid of interest to most electrical engineers. The solenoid effect magnitude is just a matter of electrical currents involved. It should be relatively easy to measure the electromagnetic effects of this large solenoid on the local magnetic field if one has the proper equipment and the good fortune to be located where a fast moving hurricane passes directly overhead. A solenoid effect measurement could be used to infer electrical charge magnitude and cloud velocities in a hurricane.

The solenoid effect due to rotating negative electric clouds is easily calculated using well
known integral techniques (Biot-Savart Law), provided the charge density and rotational characteristics are known. Figure 21 shows the nature of magnetic field lines produced by negatively charged clouds moving in a counterclockwise motion. Consider this as a cubic meter of air moving as shown:


FIGURE 21. Magnetic Field Produced by Counter-Clockwise Motion of Negative Charges.

Phenomenologically, the solenoid effect creates an induced magnetic field opposite in direction to the earth field vertical component at the outer radii of rotation; and, enhanced fields in the same direction as earth's field at inner radii. The figure 21 illustration is for a small cross-sectional area of charge motion, similar to a circular metallic conductor. For a large pancake shaped hurricane, one must add together the effects of many such circular conductors.

In fact, near the hurricane center, the collective induced magnetic field vertical component might be expected to overwhelm the earth field leading to a much higher vertical field component. The intense central field should cause the centripetal electromagnetic force (illustrated in Figure 17) to become very high, preventing the charged clouds from moving to the center of hurricane; hence, electromagnetic phenomena may very well explain why hurricanes have holes. This is very similar to the establishment of an equilibrium radius for charged particles injected into a mass spectrometer or a cyclotron; except, here there exists a self induced field. This spiraling flow cessation would seem to be consistent with the observation of almost total calm in the center of hurricanes (the"eye"). Near the hurricane eye edge, clouds moving on opposite sides of the eye
are like conductors with electrical currents flowing in opposite directions; counter-flowing electrical currents are well known to produce a repulsion effect. In addition to electromagnetic effects, Coulomb repulsion forces are important. In general for moving charges, the ratio of magnetic force to Coulomb force is $(\mathrm{v} / \mathrm{c})^{\wedge} 2$, a very large factor since c is the speed of light. Certainly, the hurricane eye is not an effect consistent with Coriolis.

As far as the solenoid effect is concerned, the earth field reinforcing effect occurs inside the circle of rotation of a charged cloud, where the induced magnetic field adds vectorially to the earth field, making the VXB effects intensified. This effect could make an electromagnetically driven storm more severe as the field builds up to values much higher than the intrinsic earth magnetic field. Because of increased severity, overall effects could easily be several times as large as can be estimated from the earth field alone. Analytical electromagnetic storm modeling should take into consideration coupling between intrinsic earth magnetic fields and induced magnetic fields from rotating masses of negatively charged clouds. Because of induced field effects and likely variation of cloud electrical charge levels with radius, the simple calculations presented herein are only qualitative.

Since the solenoid effect produces a magnetic field, an attraction to ferromagnetic materials such as the earth iron core or iron deposits is expected. Proximity of such deposits near the earth surface could thus play an electromagnetic role in hurricane pathways.

It is known that current loops (a loop of wire flowing electrical current) tend to align the loop axis with an imposed magnetic field. In the northern hemisphere, the intrinsic earth magnetic field lines point from south to north and dive into the earth surface. For a giant rotating, electrically charged cloud, one might expect the rotating cloud to align to the magnetic field, producing a tilt. The tilt would cause southern storm edges to be lower than northern edges. The reason for the tilt was illustrated in Figure 19. Such issues become complicated when induced fields begin to exceed the intrinsic earth field.

Once a solenoid has been created or energized, the induced magnetic field provides the mechanism for stored energy. The magnetic field cannot collapse instantly, but as it begins to
collapse, it tends to keep the electrical currents in motion, consistent with the nature of an electrical inductor. Energy stored in the magnetic field must be dissipated. In a copper wire inductor the energy is dissipated by $I^{2} R$ (electrical resistance) effects. In a hurricane, the dissipation would probably be through turbulent effects and rotating clouds interactions with the Earth surface. In any case, the electrical inductor effect should slow storm dissipation much as the stored rotational energy slows dissipation.

Lastly, if electromagnetic effects are significant, it might be possible to alter the dynamics of hurricanes by providing ionized pathways for discharge of electrical charges on one side or the other of hurricanes. This could be accomplished by vertically launched ion exhaust rocketry or by high intensity laser pulses. The nuclear option might include positively charged alpha particles or protons to neutralize or even reverse the cloud electrical charge and thus decouple the strongest effects. Manned intervention aside, we need only wait until the intrinsic earth magnetic field changes sign (as eventually expected) whereupon Coriolis and magnetic effects will be in opposition, perhaps entirely eliminating hurricanes. These possibilities could be exciting.

Much has been said here about the forces involved in hurricane dynamics. In this paper it is argued that electromagnetic effects and Coriolis effects happen to have the same general characteristics; this being the case because both Coriolis and Magnetic field vertical components reverse direction as one passes the equator. The solenoid action is easily calculated given information on charge density and rotational velocity as a function of radius and altitude. Inversely, local magnetic field perturbations could be used to infer information relative to the former.

Vector mathematical concepts are interesting to say the least. When the elements of magnetic field direction as well as positive or negative electrical charge are also included, it is quite easy to get things exactly backwards. Figures 3-11 and 16-19 illustrate graphically the respective effects for Coriolis and electromagnetic effects in which it is assumed that the rotational and magnetic field components are either into or out of the paper surface.

Consider a hurricane consisting of a layer of electrically charged air circulating at a high tangential velocity $\mathrm{V}_{\mathrm{t}}$ about a central zone. For the
moment include the presence of an eye, a region where there is no tangential circulation. Such a hurricane, illustrated diagrammatically in figure 22, looks like a donut that has been stepped on:

## $(\mathrm{q} / \mathrm{m})=0.17 \mathrm{C} / \mathrm{kg} \quad \rho=1 \mathrm{~kg} / \mathrm{m} 3$ <br> $\mathrm{Vt}=60 \mathrm{~m} / \mathrm{sec}$ <br> 

FIGURE 22. An Assumed Hurricane Geometry for Analysis.

In Figure 22, the rotating mass of air is assumed to be electrically charged and hence capable of inducing a magnetic field. It acts as a "pancake" solenoid. For purposes of this analysis, the presence is assumed of only the smaller $0.17 \mathrm{C} / \mathrm{kg}$ electrical charge characteristic of industrial paint spray systems. Using the geometry above, it is simple to compute the induced magnetic field at the center radius using the Biot-Savart law:

$$
\begin{equation*}
\mathrm{dB}=\mu_{\mathrm{o}} \mathrm{l} /\left(4 \pi \mathrm{r}^{3}\right) \mathrm{d} \mathbf{s} \mathbf{x} \mathbf{r} \tag{27}
\end{equation*}
$$

Where the permeability constant $\mu_{0}$ is $1 \times 10^{-7} \mathrm{Tm} / \mathrm{A}$ (Tesla-meter/Ampere), $I$ is the current in amperes for a hurricane sub-element of height $h$, differential radius dr and moving at a tangential velocity $\mathrm{V}_{\mathrm{t}}$. The quantity $s$ is the sub-element path-length, $\mathrm{ds}=\mathrm{rd} \tilde{\theta}$ The electrical current in an area of dimension dr*dh is given by

$$
\begin{equation*}
\mathrm{I}=(\mathrm{q} / \mathrm{m}) \rho \mathrm{V}_{\mathrm{t}} \mathrm{dr} \mathrm{dh} \tag{28}
\end{equation*}
$$

For $\mathrm{dr}^{*} \mathrm{dh}=$ one square meter, a charge density of $0.17 \mathrm{C} / \mathrm{kg}$ and an air density $\rho$ of $1 \mathrm{~kg} / \mathrm{m} 3$, and tangential velocity of say $\mathrm{V}_{\mathrm{t}}=60 \mathrm{~m} / \mathrm{sec}$ the current is $(\mathrm{q} / \mathrm{m}) \rho \mathrm{V}_{\mathrm{t}}=0.17^{*} 1^{*} 60=10$ amperes. This is quite a respectable current, compared to the typical household having about a 200 ampere main circuit breaker.

For simplicity, one can first compute only the induced field magnitude at the very hurricane center. In this case, for negatively charged counter-clockwise rotating clouds, the vector B will point upward, and the vector cross product dsxr magnitude will be just the scalar value rds.

Substituting into the BS law values for I and ds and using the scalar relation results in the following:

$$
\begin{align*}
\mathrm{dB} & =\mu_{\mathrm{o}} \mathrm{l} /\left(4 \pi \mathrm{r}^{3}\right) \mathrm{rds} \\
& =\mu_{\mathrm{o}}(\mathrm{q} / \mathrm{m}) \rho \mathrm{V}_{\mathrm{t}} \mathrm{dr} \mathrm{dh} /\left(4 \pi \mathrm{r}^{3}\right)(\mathrm{r} \mathrm{rd} \mathrm{\theta}) \tag{29}
\end{align*}
$$

$$
\begin{equation*}
\mathrm{dB}=\mu_{\mathrm{o}}(\mathrm{q} / \mathrm{m}) \rho \mathrm{V}_{\mathrm{t}} /(4 \pi \mathrm{r}) \mathrm{d} \theta \mathrm{dh} \mathrm{dr} \tag{30}
\end{equation*}
$$

When this expression is integrated over the Figure 22 hurricane volume, including $\theta=0$ to $2 \pi, r=r_{i}$ to $r_{0}$ and $h=0$ to $H$, and assuming a constant tangential velocity, the following is obtained as a preliminary estimate of induced magnetic field at the center of a hurricane:

$$
\begin{equation*}
B=\left[\mu_{0}(q / m) \rho V_{\mathrm{t}} / 2\right] H \operatorname{Ln}\left(r_{o} / r_{\mathrm{i}}\right) \tag{31}
\end{equation*}
$$

The quantity in brackets is approximately $10^{-7 *} 0.17^{*} 1^{*} 60 / 2=5 \times 10^{-7}$ and the remaining quantities are approximately $4000 \mathrm{Ln}(10)=10,000$, giving:

$$
\begin{equation*}
\mathrm{B}=0.005 \text { Tesla } \tag{32}
\end{equation*}
$$

A more realistic evaluation might use the equation (13) tangential velocity profile previously estimated for Coriolis induced hurricanes, $V_{\mathrm{t} .}=\Omega^{*} \operatorname{Sin}\left(\text { Latitude }^{\circ}\right)^{*}\left(r_{\text {max }}^{2}-r^{2}\right) / r$. However, the purpose of this writing is just to introduce the thought that electromagnetic effects can play a role.

The field strength of 0.005 Tesla is certainly quite small compared to a 1T (one Tesla) junkyard magnet, so it can not be expected to pull steel nails out of roofs, or lift steel automobiles off the ground (Had a 20C/kg charge been assumed for shock value, the field might easily be able to lift an automobile). However, even with the $0.17 \mathrm{C} / \mathrm{kg}$ charge, when compared to the nascent earth magnetic field of $41,000 \mathrm{nT}$ (nano-Teslas), the induced field is more than one hundred times larger! The induced field vector points in the same direction as the nominal Earth field (see Figure 21) and induced field interaction with the negatively charged rotating clouds would produce a radial outward force (see Figure 17) to resist the converging charged clouds approaching the hurricane center. It is no surprise therefore that charged clouds with high tangential velocity come to a screeching halt as they approach the hurricane center resulting in an "eye" effect. If the
magnetic and electrostatic (Coulomb) repulsion near the eye edge are high enough, the clouds might be expected to begin a radially outward motion wherein the Coriolis and Electromagnetic effects will reverse, eventually resulting in reverse circular motion. Certainly, there would seem to be no "Coriolis" explanation of rapid deceleration and the eye effect.

It is a bit more difficult to estimate the induced magnetic field as a function of radius off the hurricane center. However, since it is postulated that the electromagnetic effects are self negating at outer radii, it is worth the effort to estimate the effect. For this estimation, one need consider only the vertical magnetic field component as a function of radius at the hurricane plane.

Before computing the magnetic field from a model hurricane, it is intuitively beneficial to consider the magnetic field from a distributed current source and from a discreet current source. If the current is flowing in a very small diameter but infinitely long wire, the field a distance $x$ outside the wire is obtained by integrating the BS law to obtain:

$$
\begin{equation*}
B=\mu_{o} I /(2 \pi x) \tag{33}
\end{equation*}
$$

On the other hand, If the wire of interest is a uniformly distributed current in a wire of width $\Delta \mathrm{X}$, zero thickness and infinite length (imagine a ribbon conductor made up of many wires each flowing current), it is found from BS integration that the field a distance $x$ from the center of this wire is:
$B=\mu_{o} \mathrm{I} /(2 \pi \Delta \mathrm{X}) \operatorname{Ln}\{\mathrm{ABS}[(\mathrm{x}+\Delta \mathrm{X} / 2) /(\mathrm{x}-\Delta \mathrm{X} / 2)]\}$
Since this flat wire might also be a thin, charged cloud moving at a high velocity, and hence effectively carrying an electrical current, the equation above would be relevant. For the two types of wire (thin and unit width distributed), a field plot as a function of $x$ is shown in Figure 23.


Figure 23. Magnetic Fields from a Thin Wire and from a Distributed wire made up of
many individual conductors in parallel(to Avoid Hall Effect).

It is noted in Figure 23 that the field changes sign on opposite sides of the wires, as expected. The red filled rectangle in the center of Figure 23 is meant to be the distributed current flow, while the small diameter black spot is the small wire. There are field spikes very near the single wire and very near both edges of the distributed current. The spikes are not likely in a hurricane cloud moving at velocity, since the cloud is not likely to have highly defined edges.

Using the same BS law, one can integrate over the assumed Figure 22 200km diameter model hurricane volume. This is at best a cumbersome integral to perform analytically, so it was integrated numerically (assuming all charge and rotation to occur in an effectively thin hurricane). The results are shown in Figure 24, where the computed field is highly negative (same direction as Earth field) at the hurricane center (more than 100 times larger in magnitude than the earth field, as calculated previously), but at radii greater than about 70km the field is in the opposite direction as the earth field. At outer radii the induced field thus decreases the counter-clockwise rotational effects, while at inner radii the opposite occurs. In Figure 25, the data are plotted on a Log[ABS(InducedField/EarthField)] (Logarithm of the field Absolute value divided by the earth field magnitude).


Figure 24. Induced Magnetic Field from the Fig. 22 Model Hurricane.

Note toward the central portions ( 70 to $>100 \mathrm{~km}$ ) of the Figure 24 induced field profile there is a large increase in the field in the positive (upward) direction. This field is opposite in direction compared to the ambient earth field. Thus, the effects shown in Figures 15 through 19 would
actually be reversed. This reversing effect would tend to reverse the counterclockwise motion by virtue of a left turn rather than a right turn, and it would tend to make the charged clouds rise rather than fall in reverse of the Figure 19 diagrams.

Induced Magnetic Field


FIGURE 25. Logarithmic Plot of Induced Field.
Note that the sharp field spikes near the hurricane edges are similar to the field spikes near the edges of a distributed conductor (Figure 23); however, since the edges of a real hurricane are probably diffuse, one should expect not to see spikes.

These field profiles are for a very simple assumed hurricane velocity and charge profile having the characteristics previously postulated. The high values are consistent with large effects that could lead to very destructive hurricanes. The magnetic field profile shown is surely not characteristic of a real hurricane, since it is based upon a very simple hurricane model. A completely coupled model incorporating both Coriolis, electromagnetic, and electrostatic effects would yield a more realistic result.

It should be noted that outer radii the assumed "mature" hurricane induced magnetic field is opposite the Earth field direction. This would mean that the counter-clockwise motion at the model hurricane outer limits would actually be resisted by the electromagnetic field effects. Also, at the outer reaches, the reverse electromagnetic fields would pull the clouds toward the center, opposite to the figure 17 vector forces. However, in the mature model hurricane middle, the field would be greatly enhanced in the direction as the Earth field, and the Figure 17 outward push effects would be amplified rather than reversed. This is, of course,
a manifestation of Newton's $3^{\text {rd }}$ law, regarding equal and opposite forces and reactions.

Since the induced field tends to offset the ambient earth magnetic field effects, it is expected that the system should approach an equilibrium condition, in the presence of magnetic effects and the absence of Coriolis effects. Obviously, a comprehensive hurricane model including magnetic fields would asymptotically approach a quasi steady state situation. In this case, the induced fields would be less than the simple model shown here.

A comprehensive model including multiple effects (Coriolis, electromagnetism, static electrical attraction/repulsion, water condensation phenomena, linear and rotational fluid dynamics, and cloud charging) might lead to a hurricane structure with a more rational magnetic field profile. Most certainly, it would seem that field profile measurements would be worthwhile. Field profile measurements can be used to infer cloud electrical charges and velocities.

## 8. ELECTROSTATIC EFFECTS.

In addition to the gross electromagnetic effects, there are other effects of interest. Two wires in close proximity, flowing electrical current in the same direction tend to magnetically attract each other by virtue of well known physics that are earth magnetic field independent. The electromagnetic force on a wire length $\Delta L$ for two small parallel infinitely long wires flowing currents $I_{1}$ and $I_{2}$ and separated by a distance x is given by:

$$
\begin{equation*}
\mathrm{F} / \Delta \mathrm{L}=\mathrm{I}_{1} \mathrm{I}_{2} / 2 \pi \mathrm{x} \tag{35}
\end{equation*}
$$

Clouds surrounding a hurricane often develop into streaks that would produce mutual attraction by this mechanism. For charged clouds moving at a distance x , parallel to each other with crosssectional areas dA, length ds, density $\rho$ and charge per unit mass of $\mathrm{q} / \mathrm{m}$, the BS equation shows a force of

$$
\begin{equation*}
\mathrm{F}=(\rho \mathrm{dA} \mathrm{ds} \mathrm{q} / \mathrm{m})^{2} / 2 \pi \mathrm{x} \tag{36}
\end{equation*}
$$

Electrostatic effects between neighboring charged clouds are much more extreme. If the electrical current is generated by a distributed moving charge, the ratio of electrostatic (Coulomb) repulsion to magnetic attraction can be shown to be $(c / v)^{2}$ where $v$ is the cloud velocity and $c$ is the speed of light. Electromagnetic effects are
postulated to occur in hurricanes due to a net negative electrical charge on clouds. It is well known that two parallel wires carrying electrical current are attracted or repelled by electromagnetic effects if the electrical current is in the same or opposite direction, respectively. The force per unit length for two infinitely long parallel wires carrying currents $I_{1}$ and $I_{2}$, separated by a distance x is given by:

$$
\begin{equation*}
F_{M} / \Delta L=\mu_{0} I_{1} I_{2} / 2 \pi x \tag{37}
\end{equation*}
$$

If current is carried by a loop of wire, wire segments on opposite loop sides appear to be carrying current in opposite directions and hence they would repel each other. This is exactly analogous to the forces described previously in figure 17. In an electrical wire, electrical current is carried by the myriad of "loose" electrons in the wire; but, the net electrical charge on the wire can be nil since the negative charge of electrons is offset by positive stationary charges. The net result is that there need be no electrostatic repulsion between the wires (unless one foolishly charges the wire to a high voltage), and the electrons in the wire typically move at less than $1 \mathrm{~cm} / \mathrm{s}$ (see e.g., http://www.newton.dep.anlgov/askasci/phy99/phy9 9092.htm ).

However, for electrical current carried by a moving cloud, it is probably unlikely for electrons to jump from particle to particle, so the electron velocity is effectively the cloud velocity (possibly hundreds of $\mathrm{km} / \mathrm{s}$ ). Consider wo infinitely long negatively charged cloud streams, each of cross section A, moving parallel to each other in the same direction at velocity V . The electromagnetic attraction is given by the above relationship, where the current is $\mathrm{I}=\mathrm{AV} \mathrm{\rho}(\mathrm{q} / \mathrm{m})$, so the relationship describing the attractive electromagnetic force between the two cloud streams becomes:

$$
\begin{equation*}
\mathrm{F}_{\mathrm{M}} / \Delta \mathrm{L}=\mu_{0}[\mathrm{AV} \rho(\mathrm{q} / \mathrm{m})]^{2} / 2 \pi \mathrm{x} \tag{38}
\end{equation*}
$$

However, in the case of electrically charged cloud streams it is important to consider electrostatic (Coulomb) forces between the two streams. The electrostatic forces are very high. The repulsive force between two collections of charge separated by a distance $s$ is given by Coulomb's law:

$$
\begin{equation*}
\mathrm{F}_{\mathrm{C}}=\mathrm{q}_{1} \mathrm{q}_{2} / 4 \pi \varepsilon_{0} \mathrm{~s}^{2} \tag{39}
\end{equation*}
$$

For the same two infinitely long electrically charged parallel cloud streams, the electrostatic repulsion when the two segments $\mathrm{dL}_{1}$ and $\mathrm{dL}_{2}$ that are a distance s apart becomes:

$$
\begin{equation*}
\left.\mathrm{dF}_{\mathrm{C}}=[\mathrm{A} \rho \mathrm{q} / \mathrm{m})\right]^{2} \mathrm{dL}_{1} \mathrm{dL}_{2} / 4 \pi \varepsilon_{0} \mathrm{~s}^{2} \tag{40}
\end{equation*}
$$

When this equation is integrated over the infinite length of cloud stream from $+\infty$ to $-\infty$, taking account of vector direction of forces, then the net vector sum force is a repulsion, given by

$$
\begin{equation*}
\left.\mathrm{dF}_{\mathrm{C}} / \mathrm{dL}_{1}=\mathrm{F}_{\mathrm{C}} / \Delta \mathrm{L}_{1}=[\mathrm{A} \rho \mathrm{q} / \mathrm{m})\right]^{2} \mathrm{dL}_{2} / 2 \pi \varepsilon_{0} \mathrm{x} \tag{41}
\end{equation*}
$$

Taking the ratio of electromagnetic force to Coulomb (electrostatic) force:

$$
\left.\mathrm{F}_{\mathrm{M}} / \mathrm{F}_{\mathrm{C}}=\mu_{0}[\mathrm{AV} \rho(\mathrm{q} / \mathrm{m})]^{2} / 2 \pi \mathrm{x} /\{[\mathrm{A} \rho \mathrm{q} / \mathrm{m})]^{2} \mathrm{dL}_{2} / 2 \pi \mathrm{x}\right\}
$$

$$
\begin{equation*}
\mathrm{F}_{\mathrm{M}} / \mathrm{F}_{\mathrm{C}}=\mu_{0} \varepsilon_{0} \mathrm{~V}^{2}=(\mathrm{V} / \mathrm{c})^{2} \tag{43}
\end{equation*}
$$

The ratio being $(\mathrm{V} / \mathrm{c})^{2}$, as claimed previously, where the speed of light is given by the product of permeability and permittivity: $1 /\left(\mu_{0} \varepsilon_{0}\right)^{1 / 2}$.

Since the speed of light is approximately $300,000 \mathrm{~km} / \mathrm{s}$, and the typical hurricane cloud velocities run at about $300 \mathrm{~km} / \mathrm{sec}$, it must be concluded that electrostatic effects are about $10^{6}$ (one million) times as large as electromagnetic effects. However, there is no mechanism whereby electrostatic effects can introduce the classical clockwise or counter-clockwise spin characteristic of southern and northern hemisphere hurricane weather disturbances.

If electrostatic and/or electromagnetic effects are significant, it might be worthwhile to consider approaches for removing electrical charges from hurricane clouds. One approach might provide electrical pathways (laser ionization of atmospheric paths or strong alpha particle emission) to discharge the clouds. Some caution might be advised, since complete electrical charge removal might allow the hurricane hole to snap shut turning the disturbance into a tornado of gargantuan proportions, something that would really suck.

## 9. EXPERIMENTS AND EXPERIMENTAL DATA.

As an additional thought, the classical experiment determining rotational direction of water draining from a sink is often discussed in the literature, with the influence of Coriolis typically being relegated to inconsequential. Consider that the surface of water can be either positively or negatively charged (an effect that generally does not seem to be discussed, considered, or evaluated in such experiments). It is relatively easy to electrically charge a vessel of water relative to the earth. If the charge is significant, the same arguments applied to hurricanes in this paper would seem to apply to draining water (especially if the water is distilled and hence non-conductive). Thus, due to electromagnetic interaction with the earth field, highly negatively charged surfaces converging toward the drain should rotate counterclockwise in the northern hemisphere, while positively charged surfaces should rotate the opposite direction; viceversa in the southern hemisphere. This would be a simple, inexpensive, and interesting experiment, especially if the voltage charge sign is reversed to reverse the rotational direction.

The electrical charge on clouds is a key element in the subject matter of this paper. Clouds are made up of microscopic water particles, each capable of holding significant electrical charge. Electrical charge measurement is an important consideration. The apparatus of Figure 26, installed in an aircraft, is proposed. The apparatus consists of electrically insulated inlet and outlet tubes. A pump can be used to iso-kinetically aspirate particle laden cloud material through the apparatus. The apparatus heart is a small cyclone separator that forces particles larger than 3 to 5 microns to the outer heated cyclone wall. At the (heated) cyclone wall, the particles are melted and/or collected on the surface where they subsequently drain to the collector vessel below the cyclone cone. An electrically isolated pump is used to pass moisture laden gas through the system. The cyclone and collector are electrically isolated from the aircraft body, except for circuitry to measure the electrical current. Because the collected liquid has very low electrical capacitance compared to the inlet moisture particles, the cyclone would quickly become charged to a very high voltage by electrons resident on the small cloud particle, and drainage of that charge through the ammeter is a direct measure of charge on the particles (exclusive of very small particles that escape the cyclone). Data consist of time integrated electrical current (Coulombs) and time integrated quantities of water collected and cloud mass (kg).


FIGURE 26. Apparatus for Measuring Charge on Cloud Particles

In spite of large system size, the Earth magnetic field is not at all constant. The reasons for this are summarized by the National Geomagnetism Program at their very excellent and detailed website:http://geomag.usgs.gov/about.php as quoted:
"The geomagnetic field is generated by electric currents located in many different parts of the Earth. In the outer core the main part of the geomagnetic field is sustained by a naturally occurring dynamo. In the mantle currents can be induced by time-dependent variations in the ambient magnetic field. In the crust the field has both induced and permanent components. And, in the ionosphere and magnetosphere electric currents are sustained through a complicated interaction with the Sun, the heliomagnetic field, and the solar wind of charged particles. The many different, and sometimes remote, sources of the Earth's magnetic field each contribute to the total field at any one particular location, with the very different physical processes in each domain giving rise to a wide variety of timedependent geomagnetic variations. $\qquad$ ."

It so happens that the National Geomagnetism Program maintains the Stennis (BSL)

## Geomagnetic Observatory at the NASA Stennis

 Space Center in Missouri nearby to the 2005 major hurricane Katrina landfall path. Stennis is located about midway between Biloxi and NewOrleans. The eye of Katrina passed almost directly over New Orleans, and about 20 miles West of Stennis. Donald C. Herzog (TEL: 303.273.8487), Data Management Task Leader from the Laboratory, graciously provided this writer with magnetic field data from the time period of Katrina. The data provided, with universal time converted to local Missouri time, are plotted on Figure 27:


FIGURE 27. Geomagnetic Data from Hurricane Katrina

At about the time the hurricane eye passed over New Orleans (9am, CDT, or 24.375 on Figure 27), a major shift is noted in the magnetic field readings. However, the noted shift seems to be of an enduring nature, quite unlike any expected from the electromagnetic analyses in this paper. According to Mr Herzog, "I am attaching a ZIP file with the raw data from the Stennis observatory around the period of hurricane Katrina. Our station was hit on August 29 and you will see an offset in the traces. This caused our $Z$ trace to go kaput, but the $H$ and $D$ traces survived, as(sic) did the separate proton magnetometer (F). The system ran for several more days on batteries, but is now still out of commission." Accordingly, this writer assumes that something like an electrical power outage probably led to the offset; though, it could have been a permanent magnetization of the magnetometer used to take the data.

## 10. CONCLUSIONS

The various physical influences affecting hurricane dynamics have been examined. The influences include water condensation, Coriolis, electromagnetic and electrostatic effects. All these effects appear to be consistent with hurricane dynamics. No data show for certain that electromagnetic effects are present; but, further
data acquisition is recommended. Even if electromagnetic effects are virtually unmeasurable, electrostatic effects that are potentially $10^{6}$ larger could still be profound. Electrostatic measurements are recommended.


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