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Hurricane intensity changes associated with geomagnetic variation

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Abstract: Recently some indications have appeared that several purely meteorological processes in the terrestrial atmosphere are dependent upon magnetosphere variations. To analyse the possible relationship with North Atlantic hurricane intensification, the authors examine geomagnetic data for ten days prior to all hurricanes over the last 50 years (1950–1999). A significant positive correlation between the averaged Kp index of global geomagnetic activity and hurricane intensity as measured by maximum sustained wind speed is identified for baroclinically-initiated hurricanes. Results are consistent with a mechanism whereby ionization processes trigger glaciation at cloud top which leads to hurricane intensification through upper tropospheric latent heat release.

Keywords: North Atlantic hurricanes, geomagnetic variation, baroclinically-initially hurricanes, Poisson regression.

1. INTRODUCTION

The idea that cosmic ray fluxes modulated by solar wind, can influence storm intensity has been examined recently (Tinsley and Beard, 1997; Tinsley and Dean, 1991). The relationship is explained through changes to the rate of freezing of supercooled water droplets by ionization processes occurring in high-level storm clouds (Tinsley and Dean, 1991). The Tinsley and Dean hypothesis suggests that "electrofreezing" increases the flux of ice crystals that glaciate clouds which leads to increases in latent heating and subsequent intensification of winter cyclones. Motivated by this hypothesis as well as by previous research on the relationship between extraterrestrial factors and the intensification of winter cyclones, here the possibility of a connection between geomagnetic variation and tropical cyclone intensity changes is examined. Based on earlier work (Elsner and Kara, 1999; Elsner *et al.*, 1999) it is suggested that such a relationship will exist only for a specific type of North Atlantic hurricane that forms generally at higher latitudes with colder cloud tops.

Hurricanes are mature tropical cyclones. Formed from low pressure areas over the warm oceanic waters, a developing tropical cyclone typically moves with the trade winds from east to west at low latitudes. A tropical cyclone reaches hurricane intensity when the rotational wind speed at 10 m above the ground exceeds 33 m/sec (65 kt) sustained over 1 min (maximum sustained wind speed). In a

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few storms the maximum sustained wind speed can exceed 80 m/sec as Hurricane *Allen* did on 3 August 1980. Hurricanes may also develop from disturbances of middle latitude origin (Hebert, 1978; Elsner *et al.*, 1996). Processes leading to the intensification of these hybrid or baroclinically-initiated hurricanes are less well understood (Hess *et al.*, 1995). Baroclinically-initiated hurricanes were originally classified as a subgroup of baroclinically-enhanced hurricanes by Kimberlain (1996). A brief description of these storms are given in the next section.

In this study all hurricanes over the North Atlantic region are examined at the exclusion of hurricanes or typhoons over other tropical-cyclone basins. The region of interest includes the Gulf of Mexico and Caribbean Sea. North Atlantic hurricanes frequently strike the Caribbean islands, Mexico, and the United States. In the United States hurricanes rank at the top of all natural hazards, rivaling major earthquakes, when measured in terms of past loss of life and property damage (Elsner and Kara, 1999). Thus understanding controls on their intensity is important to science and society.

2. DATA

Hurricanes

Meteorologists have records of North Atlantic hurricanes that date back through the 19th century. Over the last half century, these records come from a wide range of measurements including ship and land reports, upper-air balloon soundings, and aircraft reconnaissance. In the present study, data for all recorded hurricanes from 1 January 1950 till 31 December 1999 were examined. These data are archived by, and available from, the U.S. National Hurricane Center (www.nhc.noaa.gov). The date on which the tropical cyclone first reached hurricane intensity is of primary concern here. Also of importance is the eventual maximum intensity of the hurricane.

Depending on development and origin mechanisms the set of all hurricanes is divided into three basic types (Elsner *et al.*, 1996). The term "tropical-only" is used to describe hurricanes that form from tropical disturbances, such as an easterly wave (a low-altitude pressure wave that moves westward at low latitudes). Tropical cyclones with origins from tropical disturbances, but which reach hurricane intensity resulting from favorable middle latitude baroclinic influences are termed "baroclinically-enhanced" hurricanes. The term "baroclinic" refers to atmospheric processes that derive energy from thermal gradients on constant pressure surfaces. Tropical cyclones that reach hurricane intensity having originated as baroclinic disturbances, such as a middle latitude trough, are termed "baroclinically-initiated" hurricanes. A connection between solar activity and annual counts of baroclinically-initiated hurricanes has already been suggested in Elsner and Kara (1999).

In summary, for the North Atlantic hurricane data we have the following types and the total number of each type over the period of investigation:

- 154 tropical-only hurricanes (TO);
- 73 baroclinically-enhanced hurricanes (BE);
- 71 baroclinically-initiated hurricanes (BI);
- 298 total hurricanes.

Geomagnetic activity

Regular solar radiation changes affect the Earth's magnetic field. Irregular current systems produce magnetic field changes caused by the interaction of the solar wind with the magnetosphere, by the magnetosphere itself, by the interactions between the magnetosphere and ionosphere, and by the ionosphere itself. Indices of magnetic activity are designed to describe variation in the geomagnetic field caused by these irregular current systems.

The K-index is a quasi-logarithmic local index of the 3-h range in magnetic activity relative to an assumed quiet-day curve for a single geomagnetic observatory site. it consists of a single-digit 0 through 9 for each 3-h interval of the universal time day (UT). The planetary 3-h index, called the Kp, is the mean standardized K-index from 13 geomagnetic observatories located in two latitude belts between 44° and 60° in the northern and southern hemispheres.

The Kp index is widely used in ionospheric and magnetospheric studies and is generally recognized as measuring worldwide geomagnetic activity. The apparent range of the Kp index which varies from 0 to 400 was obtained from GeoForschungs Zentrum, Potsdam as a sum of the eight 3-h absolute values each day over the same 50-year period (1950–1999). The primary interest is the daily Kp index (apparent range) values on days preceding the hurricane. Daily Kp index values are averaged over the 10 days preceding the hurricane and including the day of the hurricane. Since most years have more than one hurricane, annual averages of the maximum hurricane intensity and the 11-day mean Kp index were also computed.

3. RESULTS

If extraterrestrial factors can intensify a hurricane then we should expect to see a correspondence between the maximum intensity of the hurricane and the Kp index averaged over days prior to the storm reaching hurricane intensity. Figure 1 shows the distributions of Kp index values averaged over the 11 days prior to, and including the day the cyclone first reached hurricane strength, as a function of maximum hurricane intensity level. Plots are shown for the three hurricane types discussed in the previous section. The average Kp index values are grouped into five hurricane intensity levels corresponding to maximum winds between 65 and 80 kt, 80 and 95 kt, 95 and 110 kt, 110 and 125 kt and greater than 125 kt. The circle on the plot is located at the median value of the Kp index. This is an estimate of the center of the distribution. The height of the box is equal to the interquartile distance (IQD), which is the difference between the third quartile of the data and the first quartile. The whiskers (dotted lines) extend to the extreme values of the data or a distance of $1.5 \times$ IQD from the center, whichever is less. Data points which fall outside the whiskers are indicated by horizontal lines.

The plot of hurricane intensity for tropical-only hurricanes indicates only a weak relationship to the Kp index. In comparison, the plot for baroclinically-enhanced hurricanes suggests a slight positive relationship, with higher intensity hurricanes associated with larger Kp index values. The positive relationship is strongest for baroclinically-initiated hurricanes. Similar plots are obtained if the daily Kp values are averaged for seven or five days prior to the hurricane.

A closer examination of the relationship between maximum baroclinically-initiated hurricane intensity and Kp index values is shown in Fig. 2. Here the Kp values are grouped into four equal length intervals (quartiles) over the range of values (the minimum 11-day averaged Kp value over the 71 hurricanes is 9.54, the maximum value is 38.18 and the mean is 19.52), where MB indicates values much below average, B indicates values below average, A indicates values above average, and MA indicates values much above average. Values of the

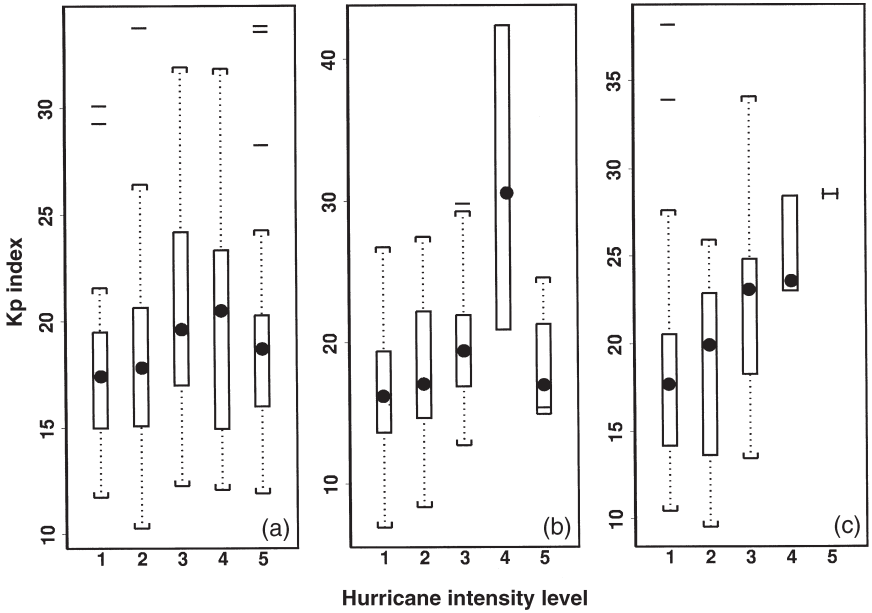

Figure 1. Distributions of 11-day mean Kp index values as a function of hurricane intensity levels for (a) tropical-only, (b) baroclinically-enhanced, and (c) baroclinically-initiated hurricanes. Hurricane intensity levels range from 1 to 5 where 1 is maximum intensity between 65 and 80 kt, 2 is maximum intensity between 80 and 95 kt, 3 is maximum intensity between 95 and 110 kt, 4 is maximum intensity between 110 and 125 kt, and 5 is maximum intensity greater than 125 kt. The 11 days include the 10 days prior to hurricane intensity plus the first day of hurricane intensity. The circle is located at the median value of the Kp index. The height of the box is equal to the interquartile distance (IQD). The whiskers (dotted lines) extend to the extreme values of the data or a distance of 1.5 × IQD from the center, whichever is less. Data points which fall outside the whiskers are indicated by horizontal lines. For intervals over which there are fewer than five data values, no whiskers are

maximum hurricane intensity tend to be higher when values of the Kp index are above normal. Note also that the variance of maximum intensity increases with increasing values of the Kp index, which is characteristic of a Poisson response variable.

To fit a model to Poisson random responses, generalized linear models (GLMs) should be used instead of linear models. GLMs enlarge the class of linear least-squares models in two ways: (1) the distribution of the response (maximum hurricane intensity) for a predictor (Kp index) is assumed to be from the exponential family, which includes the Poisson distribution; (2) the relationship between the expected value of the response and the predictor is specified by a link function which is only required to be monotonic and differentiable. The link function for the Poisson distribution is the natural logarithm of the mean of the response variable.

GLMs are examined by considering the size of the difference between the observations and fitted values through the deviance function (McCullagh and Nelder, 1989), which serves as a generalization of the usual residual sum of squares for non-normal data (Solow, 1989). Two competing models are compared by taking the difference in their respective deviance values (deviance difference). In the present case the competition is between the null model (no predictor) and a model with the Kp index as the single predictor. A large deviance difference

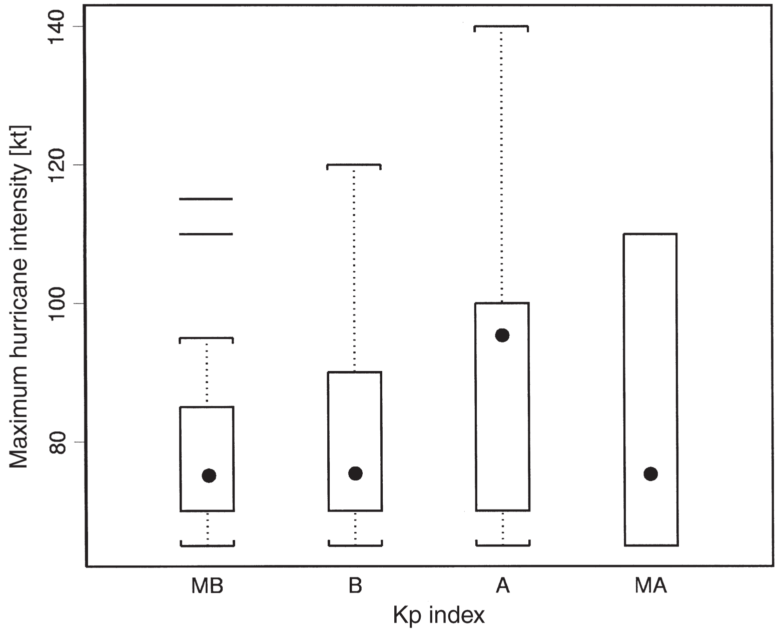

Figure 2. Distributions of maximum hurricane intensity as a function of average Kp index values. The index values are categorized into quartiles. The maximum and minimum 11-day averaged Kp index values are 38.18 and 9.54, respectively. The mean is 19.52. MB is for values much below average, B is for values below average, A is for values above average, and MA is for values much above average. Hurricane intensity shows a location shift with respect to the Kp index values. There are only three hurricanes in the 'MA' category so no whiskers are shown.

when the Kp index is added to the null model indicates an improvement when maximum likelihood estimates are used to determine model coefficients (McCullagh and Nelder, 1989). How significant the improvement is determined by a χ^2 distribution with degrees of freedom equal to the difference in the number of coefficients in the competing models.

Considering only the set of baroclinically-initiated hurricanes and comparing the null model with a model that contains the 11-day averaged Kp index (10 days before plus the day the storm first reached hurricane intensity) as a predictor we find a deviance difference of 23.94 kt with a p-value of 9.95×10^{-7} using a χ^2 test. The very small p-value indicates that we should reject the null model. Thus it appears that the average Kp index has a statistically significant relationship to the maximum intensity of the baroclinically-initiated hurricane. When Kp index values are higher, the probability of a stronger hurricane is larger.

The relationship between the geomagnetic index and hurricane intensity is investigated further by grouping the hurricanes by years. The maximum intensity of all baroclinically-initiated hurricanes are averaged for each year. Similarly the corresponding 11-day averaged Kp index values are averaged for the year. Results are plotted in Figs 3 and 4. The graphs indicate a firm statistical relationship as the two curves tend to vary in phase over time. Correlation between the annual series is +0.50. The p-value on the slope of the ordinary least-squares linear regression line in the scatter plot is 0.002, indicative of a statistically significant relationship.

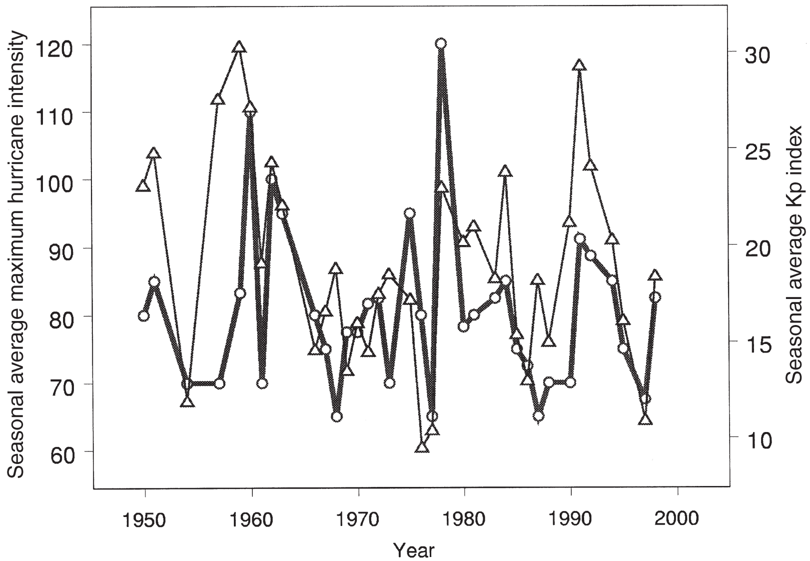

Figure 3. Time-series graphs of the annual averaged maximum hurricane intensity (kt) and Kp index. Some years are void of baroclinically-initiated hurricanes and these years are not plotted on the intensity curve.

4. SUMMARY AND DISCUSSION

The study is an exploratory analysis of a possible relationship between geomagnetic activity and hurricane intensity changes. The study begins with a look at the bivariate relationship between the Kp index and changes in hurricane intensity, as measured by the maximum sustained 1-min, 10-m wind speed, for all hurricanes over the North Atlantic during the period 1950–1999. An analysis is performed on the three groups of hurricanes outline in Elsner and Kara (1999). As anticipated, based on the investigations of Elsner *et al.* (1999), a relationship is found for the baroclinic type storms only. In particular, the maximum intensity of the baroclinically-initiated storms have a statistically significant relationship with 11-day averaged (the first day of hurricane intensity plus the 10 prior days) Kp index values when modelled with a Poisson generalized linear model. Similar results are obtained when the data are averaged over all baroclinically-initiated hurricanes during the year.

Factors that cause intensification of baroclinically-initiated tropical cyclones are least understood as they are linked to the transformation from an upper-level cyclonic circulation to one featuring a warm-core anticyclonic circulation. Some cyclones make a complete transformation and intensify as full-fledged hurricanes, whereas others continue as weaker, hybrid systems. From the work of Tinsley (2000), a possible triggering mechanism for condensation and freezing within the convective clouds of the fledgling cyclone is suggested. This trigger is related to the ionization of the upper extent of the storm vortex that leads to additional latent heat release and subsequent warming of the core region of the cyclone. Central-core warming is associated with a lowering of the surface pressures and thus with intensification of the hurricane. Moreover, diabatic heating near the storm center can act to inhibit tilting of the vortex circulation against

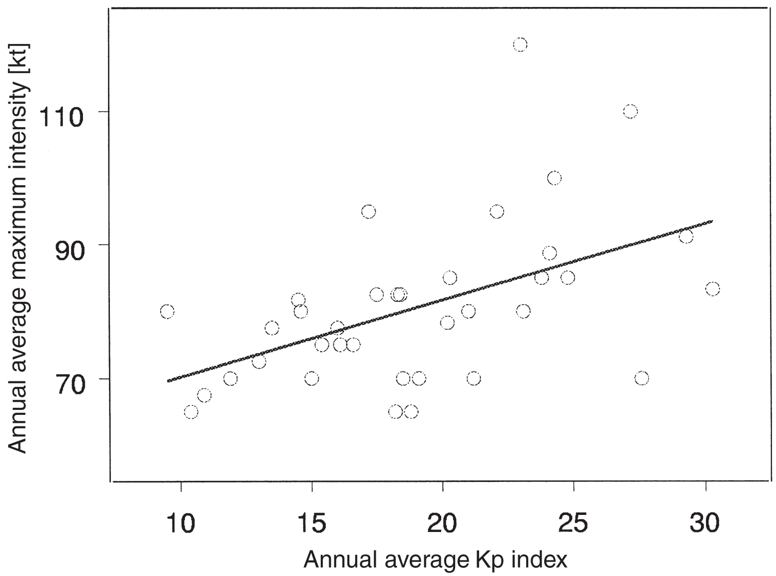

Figure 4. Scatter plot of the annual averaged Kp index values versus the annual averaged maximum hurricane intensity. The line represents the ordinary least-squares linear regression fit to the data.

debilitating vertical shear of the horizontal wind [see e.g. DeMaria (1996)]. These processes may be more important for hurricanes that form outside the deep tropics as is the case with baroclinically-initiated hurricanes. More work is needed to better understand this intriguing result.

References

DeMaria, M., 1996. The effect of vertical shear on tropical cyclone intensity change. *J. Atmos. Sci.*, **53**, 2076–2087.

Elsner, J. B. and Kara, A. B., 1999. *Hurricanes of the North Atlantic: Climate and Society*. Oxford: Oxford University Press.

Elsner, J. B., Lehmiller, G. S. and Kimberlain, T. B., 1996. Objective classification of Atlantic basin hurricanes. *J. Climate*, **9**, 2880–2889.

Elsner, J. B., Kara, A. B. and Owens, M. A., 1999. Fluctuations in North Atlantic hurricane frequency. *J. Climate*, **12**, 427–437.

Hebert, P. J., 1978. Intensification criteria for tropical depressions of western North-Atlantic. *Mon. Wea. Rev.*, **106**, 831–840.

Hess, J. C., Elsner, J. B. and LaSeur, N. E., 1995. Improving seasonal hurricane predictions for the Atlantic basin. *Weather Forecast.*, **10**, 425–432.

Kimberlain, T. B., 1996. *Baroclinically-initiated hurricanes of the North Atlantic Basin*. M.S. Thesis, Department of Meteorology, The Florida State University.

McCullagh, P. and Nelder, J. A., 1989. *Generalized Linear Models*. Chapman and Hall.

Solow, A. R., 1989. Statistical modeling of storm counts. *J. Climate*, **2**, 131–136.

Tinsley, B. A., 2000. Influence of solar wind on the global electric circuit, and inferred effects on cloud microphysics, temperature, and dynamics in the troposphere. *Space Sci. Reviews*, **94**, 231–258.

Tinsley, B. A. and Beard, K. V., 1997. Meeting summary: links between variations in solar activity, atmospheric conductivity, and clouds: an informal workshop. *Bull. Amer. Meteor. Soc.*, **78**, 685–687.

Tinsley, B. A. and Dean, G. W., 1991. Apparent tropospheric response to MeV-GeV particle flux variations: a connection via electrofreezing of supercooled water in high level clouds? *J. Geophys. Res.*, **96**, 22283–22296.