A statistical link between tropical cyclone intensification and major geomagnetic disturbances

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Resumen

Se encuentra una relación estadísticamente significante entre la actividad geomagnética y la intensificación de ciclones tropicales sobre el Atlántico tropical donde se forman la mayoría de los huracanes. El trabajo es congruente con un estudio previo relativo a la conexión entre actividad geomagnética y la intensidad de ciclones tropicales. Se amplían los resultados anteriores dirigiendo el enfoque hacia la intensificación en lugar de intensidad y el empleo de datos horarios. El resultado es de mayor generalidad, en el sentido de que no hay necesidad de separar los ciclones tropicales por categoría para interpretación.

Palabras clave: Ciclones tropicales, intensificación, disturbios geomagnéticos, eventos Forbush

Abstract

A statistically significant relationship is found between geomagnetic activity and tropical cyclone intensification over the tropical Atlantic where major hurricanes form. The result is consistent with an earlier study in showing a connection between geomagnetic activity and tropical cyclone intensity. It expands on this earlier work by focusing on intensification rather than intensity and by examining hourly data. Results appear to be more general in that there is no need to separate the tropical cyclones by type.

Key words: Tropical cyclones, intensification, geomagnetic disturbances, Forbush events.

Introduction

Variations in geomagnetic activity in the magnetosphere have been statistically linked to hurricane intensity over the North Atlantic (Elsner and Kavlakov, 2001). A positive correlation between the averaged Kp index of global geomagnetic activity and hurricane intensity as measured by maximum sustained wind speed is identified. The results were based on daily hurricane intensity. Here we examine the relationship in more detail using hourly intensification rates.

We consider the maximum wind speed (intensity) for all hurricanes and tropical storms (tropical cyclones) over the North Atlantic, which includes the Atlantic Ocean, Gulf of Mexico, and the Caribbean Sea, during the period 1951-2005. The data are derived from the HURricane DATa base (HURDAT or best-track) (Neumann *et al.*, 1999) maintained by the National Hurricane Center (NHC). HURDAT consists of 6-hourly positions and intensities. We convert the 6-hourly values to 1-hourly values using cubic spline interpolation. As an example, Fig. 1 shows the 1-hr position and intensity for Hurricane Katrina of 2005. Katrina was the deadliest hurricane to strike the United States since 1900.

Intensification (or intensification rate) is the change of intensity with time. The terms "intensifying" and "deepening" refer to positive intensification while the terms "decaying" and "filling" are used for negative intensification. Tropical cyclone intensification is a time derivative quantity. While it is tempting to use a simple finite difference procedure to approximate the derivative, the order of the error on this approximation procedure is commensurate with the derivative value. Here we estimate the hourly intensification rate from an asymmetric 6-point (3 left, 2 right) 3-degree Savitzky-Golay first derivative filter (Savitsky and Golay, 1964) that reduces the error. Hourly intensification rates are obtained for all hurricanes and tropical cyclones for a total of 105,638 values over the period 1951-2005. Fig. 2 shows a time series plot of the hourly intensification for Hurricane Katrina.

Intensification and major geomagnetic disturbances

Our interest in this study is the hurricane intensification rates around the time of a major geomagnetic disturbance and whether there is, on average, a statistically higher rate during these disturbances. The Kp index is widely used in ionospheric and magnetospheric studies and is recognized as measuring the magnitude of worldwide geomagnetic

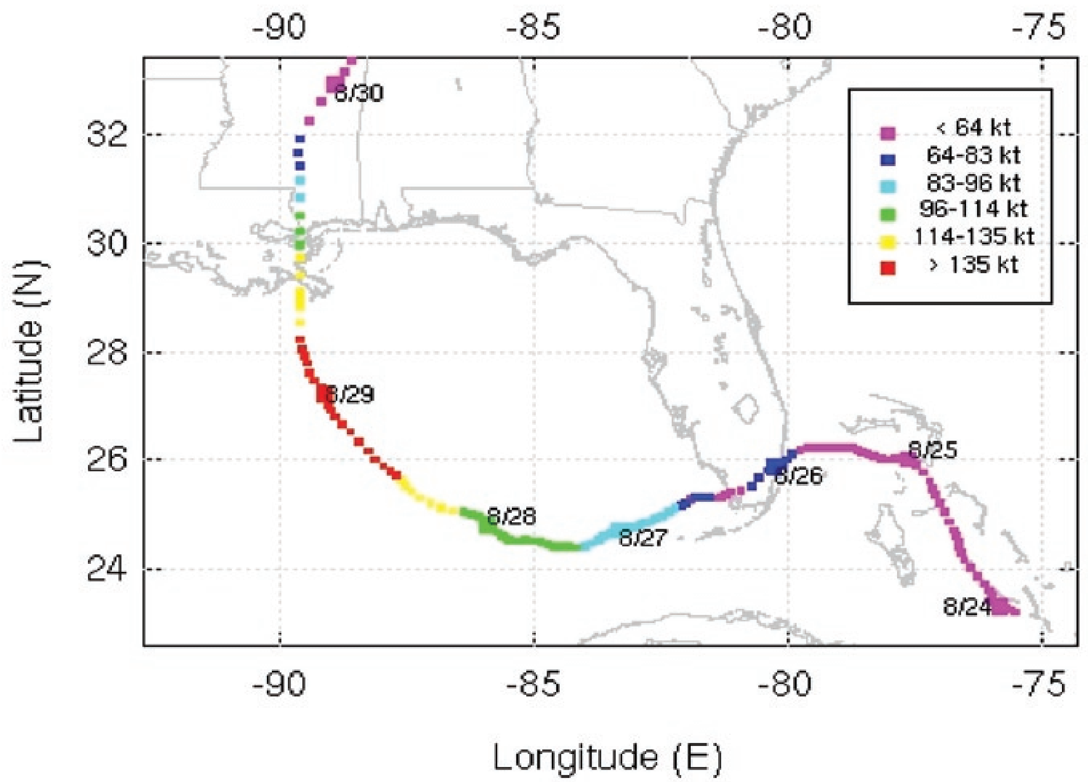

Fig. 1. Track of Hurricane Katrina of 2005. The positions are every hour (interpolated from the mostly 3 hr reports) beginning at 2100 UTC on August 23rd over the southern Bahamas. Color denotes storm intensity as indicated by the maximum sustained wind speed (kt). The date (month/day) is shown at the 0000 UTC time.

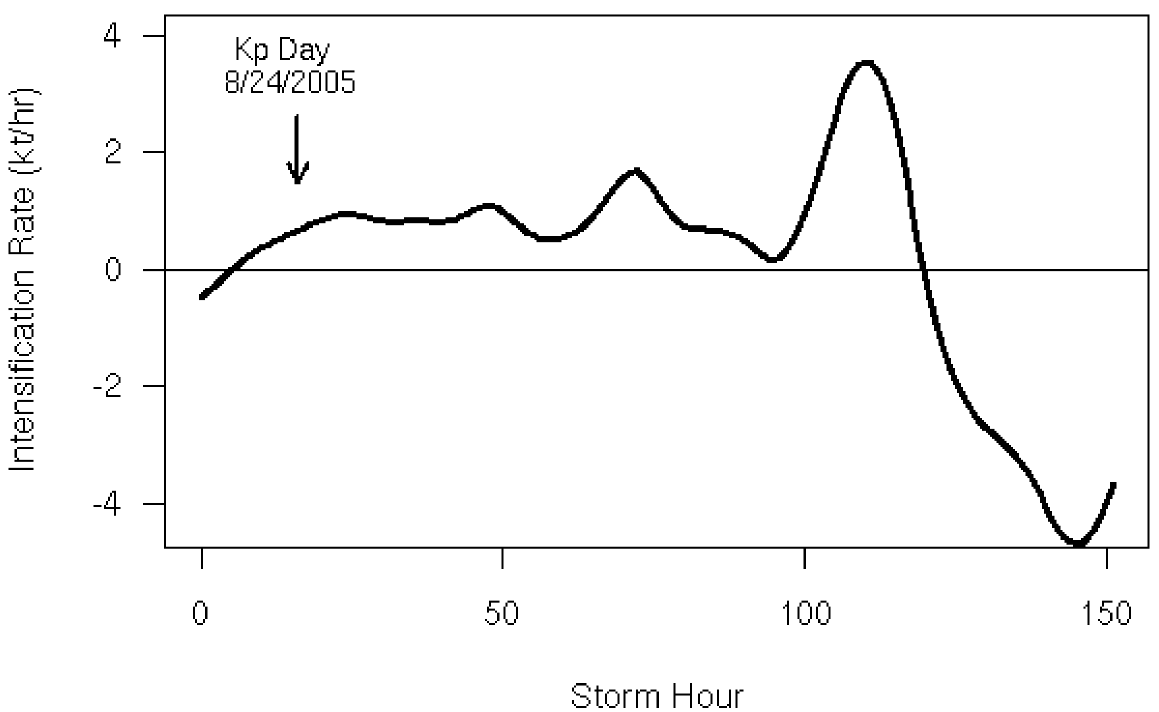

Fig. 2. Intensification rate for Hurricane Katrina. The intensification rate in kt/hr is given every hour for the lifetime of the tropical cyclone until it passes north of 33 degrees N latitude. The arrow locates a Kp day. The location is 0900 UTC on 8/24/2005 when the Kp index reached a value of 8.7 steps.

activity. Data were obtained from the U. S. National Oceanic and Atmospheric Administration (NOAA) website. Interest is on days surrounding a Kp maximum event (called here a Kp day). A Kp day is defined as one in which the daily Kp index exceeds 420 or more than 70% above the long-term average.

In this way we identify 224 Kp days during the hurricane season months of May through November over the period 1951-2005. The monthly distribution of Kp days (Fig. 3) showing how many of the 224 Kp days fall in each of the months is fairly uniform with a maximum during September and a minimum in June. The annual distribution shows the well-known 22-year solar cycle. There is no significant long period trend in these counts. In contrast, the hurricane season is strongly peaked around the month of September and there is an increasing trend over time in the number of tropical cyclone hours (Fig. 4).

We statistically analyze the relationship between geomagnetic disturbances and hurricane intensification by averaging intensification rates over 5 days centered on the Kp day and comparing this mean intensification with the overall average intensification. From all 105,638 hours of tropical cyclone activity, the mean intensification rate is +0.0342 kt/hr which equals 4.1 kt over any 5-day period. This compares with a mean intensification rate of +0.0713 kt/hr or 8.56 kt over the 5-day period based on 10,995 hours of intensification (108 separate tropical cyclones) plus and minus 2 days of the Kp day. We note larger intensification rates surrounding the Kp day, on average, for tropical cyclones weaker and stronger than hurricane intensity (64 kt).

To test the significance of these differences we randomly assign days as Kp days and compare the mean intensification rate (bootstrapped rate) over the 5 days centered on these random dates. We repeat this procedure many times (200-1000) and count the number of bootstrapped rates that exceed +0.0713 kt/hr. The number of times the rate is exceeded divided by the total number of bootstrapped rates is the p-value. We find a p-value of 0.12 for all cyclones, 0.13 for weak cyclones, and 0.10 for strong cyclones. While suggestive, the results are inconclusive regarding the relationship between geomagnetic disturbances and hurricane intensification.

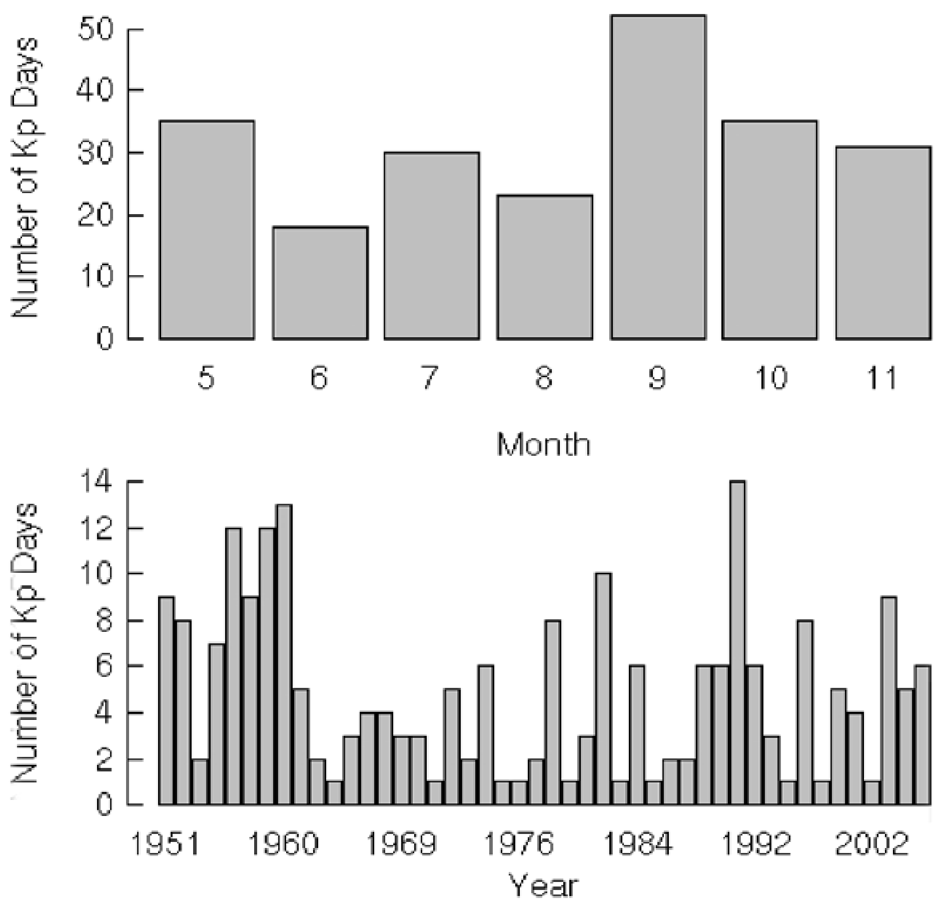

Fig. 3. Distribution of Kp days by month and year. A Kp day is defined as one in which the daily Kp index exceeds 420. By this definition there are a total of 224 Kp days in the period 1951-2005. Of those, 35 occurred during the month of May and 9 occurred in 1951.

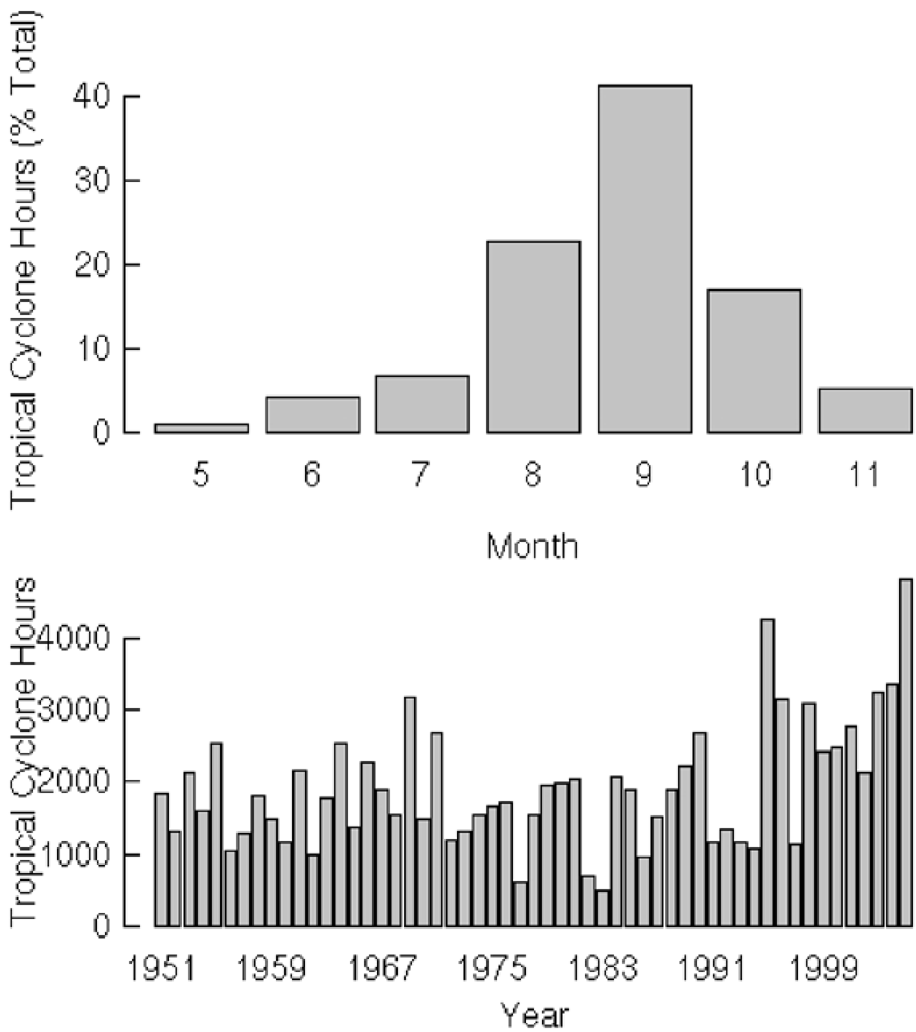

Fig. 4. Tropical cyclone hours. The monthly distribution and annual counts of tropical cyclone hours for the North Atlantic over the period 1951-2005.

Controlling for other factors

Tropical cyclone intensification depends on many factors (DeMaria and Kaplan, 1999) including oceanic heat content and proximity to land. These factors will confound our ability to identify a significant geomagnetic signal in the data. In order to provide some control, we repeat the analysis using cyclones confined to the open waters of the tropical Atlantic. In this way we control for proximity to land by considering only storm hours far from land and control for ocean heat content by considering only storm hours over a fairly uniformly warm part of the basin. The control region we choose is part of the main development region for tropical cyclones and is bounded by 25 and 60 degrees W longitude and by 8 and 23 degrees N latitude.

There are 17,579 cyclone hours within the control region over the 55-year period (1951-2005). As expected the mean intensification rate is considerably higher at 0.313 kt/hr (37.6 kt/5 days). The mean intensification for the 5 days centered on a Kp day is 0.543 kt/hr (65.1 kt/5 days). This is based on 26 separate tropical cyclones, including Tropical Cyclone Dog in 1952 and Tropical Cyclone Iris in 2001. We repeat the bootstrap procedure as described above for determining the statistical significance. Fig. 5 shows the histogram of mean intensification rates for 1000 bootstrapped rates. The actual rate is noted with an arrow. The p-value is 0.007 indicating a significant increase in intensification around Kp days relative to the average. Similar results are noted for tropical cyclones greater than and tropical cyclones less than 64 kt, although the significance is more pronounced for the weaker cyclones.

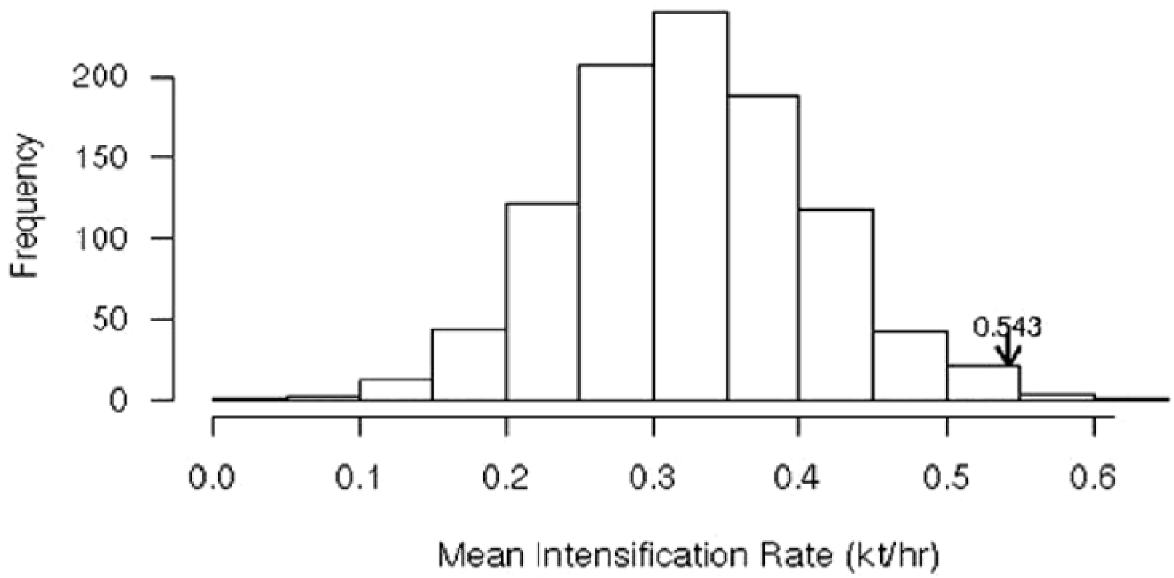

Fig. 5. Histogram of bootstrapped intensification rates over the control region. The mean intensification rate +/- 2 days of the Kp day is 0.543 kt/day, which is greater than all but 7 of the 1000 bootstrapped rates.

The 2-day window surrounding the Kp day is arbitrary so we also consider the mean hurricane intensification for storms before, during, and after the Kp day. Fig. 6 shows the mean intensification rate as a function of lag time from the Kp day. A lag of 0 represents the Kp day and minus days are days before the Kp day. We note that the effect appears most pronounced for lags from -3 to +3 days with a peak at +2 days.

Intensification and forbush events

For comparison we statistically analyze the relationship between Forbush events (FE) and tropical cyclone intensification by averaging intensification rates over 5 days centered on the FE day and comparing this mean intensification with the overall average intensification. Fig. 7 shows the distribution of FE days by month and year. A FE day is defined as one in which cosmic ray intensity drops by at least 3% at the Climax, Colorado USA cosmic ray station. The annual distribution shows the well-known 22-year solar cycle. There is no significant long period trend in the frequency of Forbush days.

As mentioned, from all 105,638 hours of tropical cyclone activity, the mean intensification rate is +0.0342 kt/hr, which equals 4.1 kt over any 5-day period. This compares with a mean intensification rate of +0.0546+/-0.0095 kt/hr or 6.5 kt over the 5-day period based on 7,691 hours of intensification (96 separate tropical cyclones) plus and minus 2 days of the FE day.

There are 17,579 cyclone hours within the control region over the 55-year period (1951-2005). As expected the mean intensification rate is considerably higher at 0.313 kt/hr (37.6 kt/5 days). The mean intensification for the 5 days centered on a FE day is 0.363 kt/hr+/-0.0216 (43.6 kt/5 days). This is based on 25 separate tropical cyclones, including Tropical Cyclone Carrie in 1957 and Tropical Cyclone Irene in 2005. Fig. 8 shows the mean intensification rate as a function of lag time from the FE day. A lag of 0 represents the FE day and minus days are days before the FE day.

Summary

Here we find a statistically significant relationship between geomagnetic activity and hurricane intensification over the tropical Atlantic where major hurricanes form. The result is consistent with an earlier study in showing a connection between Kp values and hurricane intensity. It expands on the earlier work by focusing on intensification rather than intensity. Results appear to be more general in that there is no need to separate the tropical cyclones by type as was done in Elsner and Kavlakov (2001).

Along the lines of our earlier study we suggest that a possible physical mechanism is related to increased ionization of the upper extent of the tropical cyclone vortex leading to increased condensation and additional warmth throughout the atmospheric column (Tinsley 2000). The charged particles (ions) relevant for cloud processes are

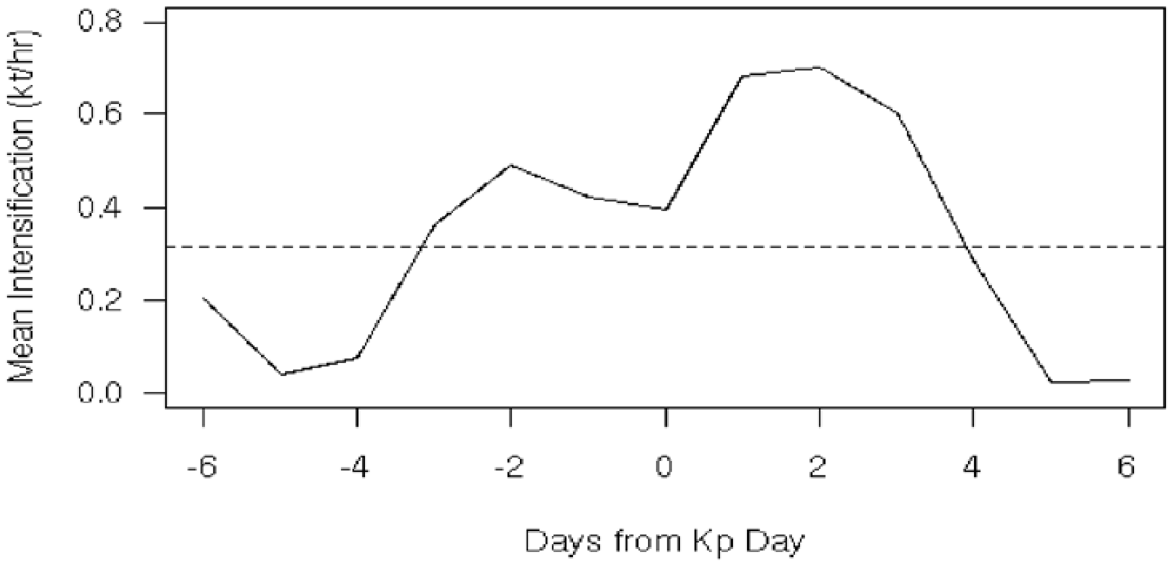

Fig. 6. Lag plot of mean intensification. The influence of the geomagnetic disturbance appears most pronounced over a 7-day period centered on the Kp day.

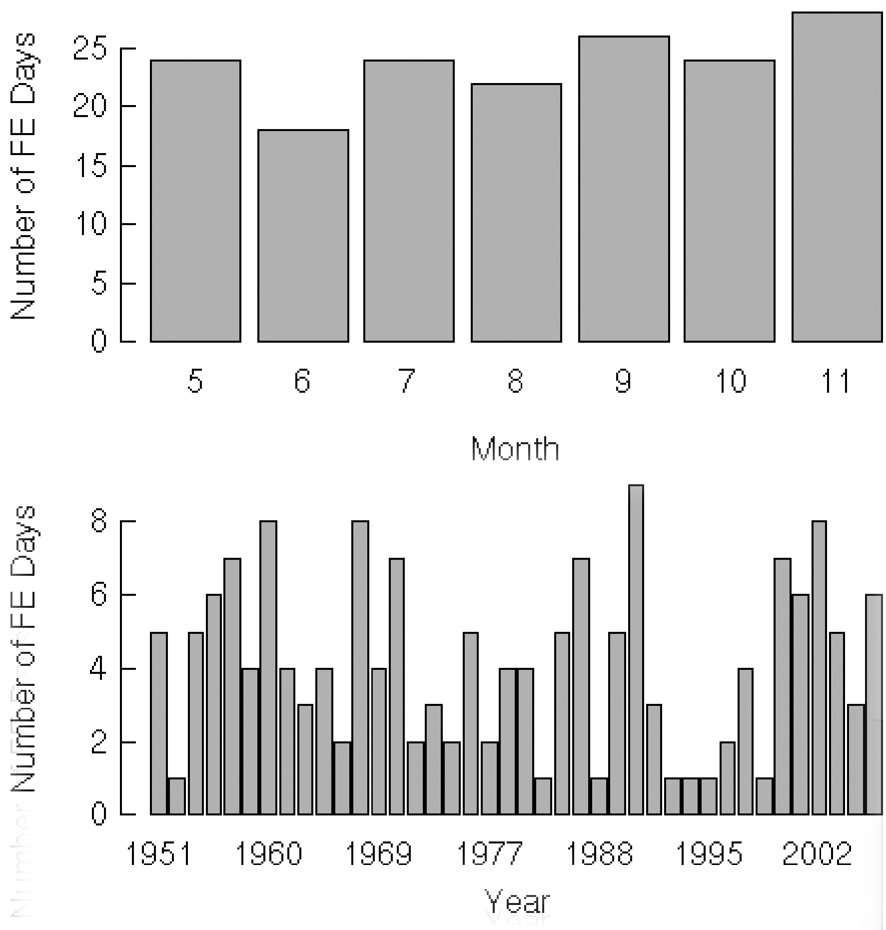

Fig. 7. Distribution of Forbush event (FE) days by month and year. A FE day is defined as one in which cosmic ray intensity drops by at least 3%. The annual distribution shows the well-known 22-year solar cycle. There is no significant long period trend in the frequency of Forbush days.

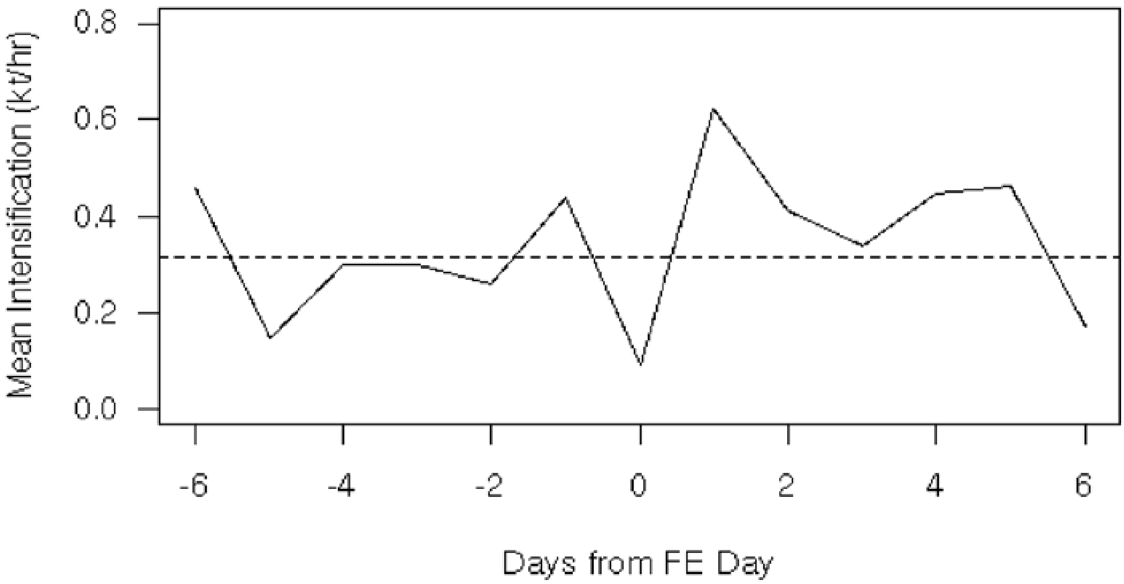

Fig. 8. Lag plot of mean intensification. The influence of the cosmic rays on tropical cyclone intensification appears less pronounced than that of geomagnetic variation.

generated by galactic cosmic rays and modulated by geomagnetic activity. Charged particles (ions) can provide condensation sites for water vapor to produce aerosols that under the right conditions can grow to sizes sufficient for additional growth as cloud condensation nuclei. Droplet growth by condensation heats the upper central core of the vortex.

Central-core warming is associated with a lowering of the surface pressures and thus with intensification of the tropical cyclone. No significant relationship with hurricane intensification is found for cosmic rays as defined by Forbush events. Obviously more work is needed to better understand this interesting result.

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