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Some statistical connections between the cosmic ray intensity, solar activities, geomagnetic changes and hurricane intensification

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Abstract.
Recently some indications appeared that several purely meteorological processes in the terrestrial atmosphere are connected with the changes in cosmic ray (CR) intensity, are influenced by solar activity; and are dependent on magnetosphere variations (Tinsley, 2000; Tinsley and Beard, 1997).

To analyze these possible relationships to North Atlantic hurricane formation and intensification, we examine data on CR intensity variations, sunspot (Ss) numbers, and geomagnetic index (KP) for several days preceding the hurricane. All recorded North Atlantic hurricanes in the last 50 years (1950-1999) are analyzed.

A decrease in CR intensity is noted on the day of hurricane formation and sunspot activity shows a local maximum several days before hurricane intensity is reached. Neither of these results stands above the nominal statistical significance level. In contrast a significant positive correlation between the KP index and maximum hurricane intensity is established.

1. Introduction.

A counterclockwise (clockwise) rotation of air is called a cyclone in the Northern (Southern) hemisphere. Formed from low pressure over the hot oceanic waters near the equator, a developing tropical cyclone typically moves with the trade winds from east to west. A tropical cyclone reaches hurricane intensity when the rotational wind speed near the center of the storm exceeds 33 m/sec (65 kt) (see **Table 1**).

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Table.1. General characteristics of North Atlantic hurricanes.

Storm diameter:	200- 1300 km	Eye diameter:	16 – 70 km
Energy Source:	Latent heat release	Lifespan:	1 – 30 days
Kinetic energy:	4-8 TWh	Surface winds:	> 33 m/sec

In some storms the wind velocity can exceed 80 m/sec as hurricane Allen did on August 3rd, 1980. In this case the estimated power surpassed the power of nearly 100000 bombs – Hiroshima type.

Here we examine hurricanes over the North Atlantic region and do not consider hurricanes, or typhoons over the other tropical-cyclone basins (e.g. western North Pacific). 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 the major earthquake, when measured in terms of past loss of life and property damage.

That is why understanding the formation and intensification processes, involving all possible connections with accompanying meteorological physical, geophysical, and heliophysical factors is important, not only for the scientists, but for the people in these vulnerable areas.

2. Data.

2.1. Hurricanes.

Meteorologists have records of North Atlantic hurricanes that date back into the 19th century. Over the last half-century, these records are based on a wide range of measurements including ship and land reports, upper-air balloon soundings, and aircraft reconnaissance.

In this work data were used for all recorded hurricanes from January 1, 1950 till December 31, 1999 with exact dates of hurricane intensity (D1), of maximum intensity (D2) along with corresponding geographical positions [B *(ö1, ë1)*] and [*C (ö2, ë2)*].

Depending on development and origin mechanisms, the set of all hurricanes was divided into 3 basic types (Elsner et al. 1996). The term "tropical-only" (TO) 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"(BE) 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 a baroclinic disturbance, such as a middle latitude trough, are termed "baroclinically-initiated" (BI) hurricanes. A connection between solar activity and annual number of hurricanes has been suggested for BI hurricanes (Elsner and Kara 1999).

Thus, here, three types of hurricane data were analyzed:

154 Tropical-only hurricanes (TO);

73 Baroclinically-enhanced hurricanes (BE);

71 Baroclinically-initiated hurricanes (BI).

2.2. Cosmic Rays

Cosmic ray measurements were first undertaken during the International Geophysical Year (1957), but the detectors, electronics, and recording techniques, used in these first years, were below stability requirements. That is why different sets of CR intensity data were checked and compared. The Neutron Monitors CR intensity data were chosen as appropriate for comparison, because of their continuity and stability.

Cosmic ray stations for continuous intensity measurements are outside the North Atlantic basin, but our comparisons show that the general trend of CR intensity changes from day to day is well correlated for all nearby stations in Canada, United States, and Europe. Here we use the daily averaged CR intensities measured in Oulu (65.05N; 25.47E), Finland. These data are kindly posted on the Oulu University website for the period from April 1964 through December 1999.

2.3. Sunspot Numbers.

The full set of daily sunspot numbers for the period 1950-1999 was obtained from the website of the National Geophysical Data Center in Boulder, Colorado, USA.

2.4. Geomagnetic Activity Index.

Here the KP index for geomagnetic activity was used. The index was obtained from the website GeoForschungs Zentrum, Potsdam as a sum of the 8 absolute 3-hourly values each day over the same 50-yr period. The primary interest was data for days preceding the hurricane.

3. Data processing.

3.1. Hurricanes.

For all 298 North Atlantic hurricanes the date and location, where the storm first reached 33 m/sec, were elaborated. The date and location, where the hurricane reached its maximum intensity were also examined. Track length for each hurricane is calculated as the shortest distance (L) between the point B (*ö1, ë1*) and C (*ö2, ë2*), using spherical trigonometry as:

$$L = R \arccos\{\cos(90-ö1)\cos(90-ö2) + \sin(90-ö1)\sin(90-ö2)\cos(ë2-ë1)\}, \quad (1)$$

where *R* is the Earth's radius. The hurricane time duration (D) in days is the difference D = (D2 – D1). These data are stratified by hurricane type as described previously.

3.2. Corresponding values.

For the day of the hurricane and for the nine days prior to it corresponding values for CR intensity, Ss number, and KP index were compared. A 10-day mean for each of the three variables, consisting of the average over the days prior to and including the hurricane day, was calculated. Since most years have more than one hurricane, annual averages were also considered. Annual averages are computed for the hurricane data (e.g. for Vmax) and for the corresponding 10-day mean geophysical values.

4. Results.

4.1. Preceding days.

CR intensity values on the day of the hurricane and the nine preceding days were averaged for each type of hurricane and shown in **Fig. 1**. There is a tendency for a sudden decrease in CR intensity on the day the storm reaches hurricane intensity. It occurs after a relative higher intensity during the preceding several days for TO and BI storms. It was also observed that, for more than 70% of all hurricanes the CR intensities, averaged over the preceding nine-day period, are below the corresponding monthly mean CR intensities.

In comparison, the sunspot numbers during the preceding days tend to reach a maximum between 4 and 6 days before hurricane intensity is reached for the TO and BI hurricanes **(Fig. 2)**. Similarly, there are no statistically significant changes in the KP index over the days preceding the hurricane.

4.2. Corresponding values.

If hurricane intensity is influenced by extraterrestrial factors, then one should expect to see a correspondence

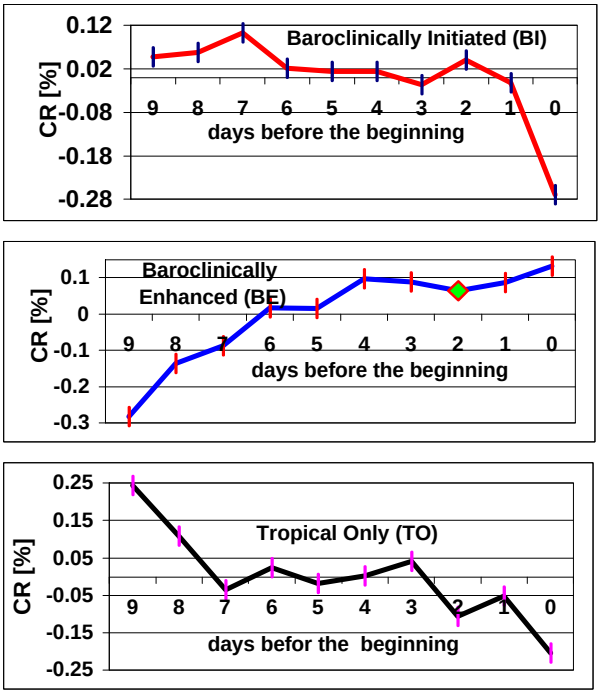

Fig. 1. Averaged CR intensity on days before the hurricane. Values are averaged over all hurricanes of the specified type.

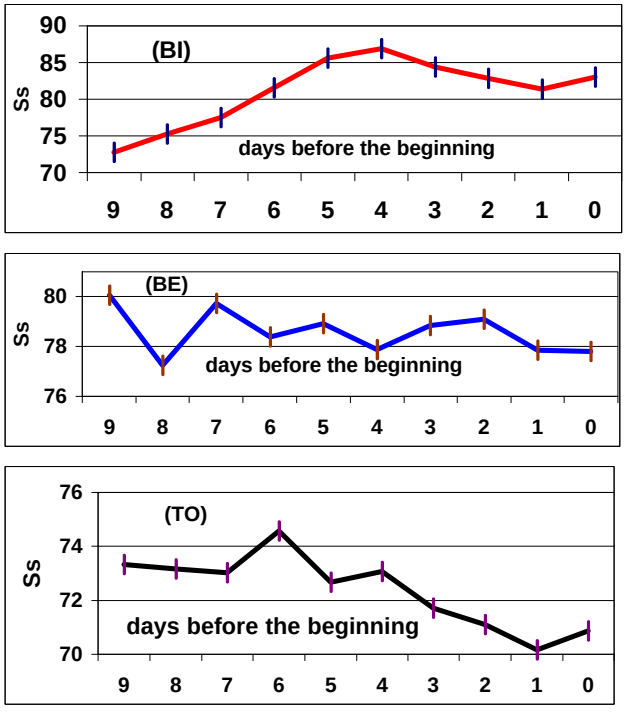

Fig. 2. Averaged sunspot numbers on days before the hurricane. Values are averaged over all hurricanes of the specified type.

between values of CR intensity, Ss number, or KP index and maximum hurricane intensity. Correlation coefficients between the maximum hurricane intensity and the ten-day averaged values of CR intensity, Ss number, and KP index were calculated. For comparison the correlations with path length (L) and hurricane duration (D) were also calculated. In general, the coefficients are less than 0.2, with the exception of the correlation between BI hurricane intensity and the geomagnetic KP index where the value is 0.33.

This apparent association was investigated in more detail by modeling the relationship, using Poisson regression. The model is significant with a *p*-value of less than 0.001. The *p*-value arises from the probability of the ÷-squared value, being less than the deviance difference with a single degree of freedom. A scatter plot of the relationship is shown in **Fig. 3**. It is noted that, as the KP index increases, Vmax increases too, but there is large scatter to the points.

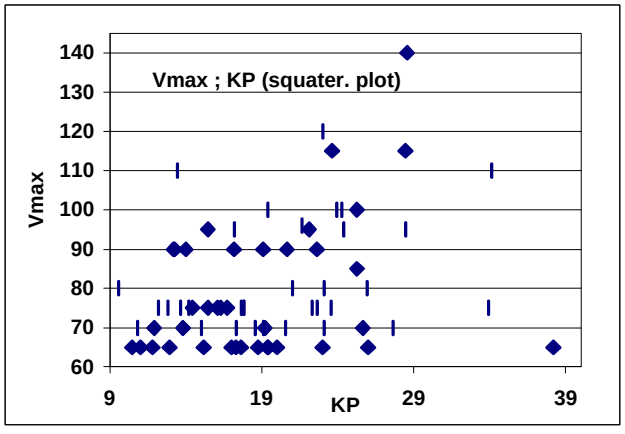

Fig. 3. Scatter plot of maximum hurricane intensity as a function of the 10-day averaged KP index. The averaging is done over the 10 days prior to hurricane intensity.

4.3. Annual values.

Since in general more than one hurricane of a given type will occur each year, the above relationships using values averaged by year were examined. As expected, the correlations are below 0.2 with the notable exception of the KP index, which obtains a value of 0.50. The annual averaged values of maximum intensity and KP index are plotted in **Fig. 4**. The graph indicates a possible relationship, as large values of Vmax tend to coincide with large values of the KP index.

A negative correlation (-0.49) between accumulated maximum intensity of hurricanes type BI and CR was found (**Fig. 5**.).

5. Discussion.

The possibility of an extraterrestrial connection to hurricanes was examined. Hurricane characteristics studied include the maximum rotational velocity, the duration of

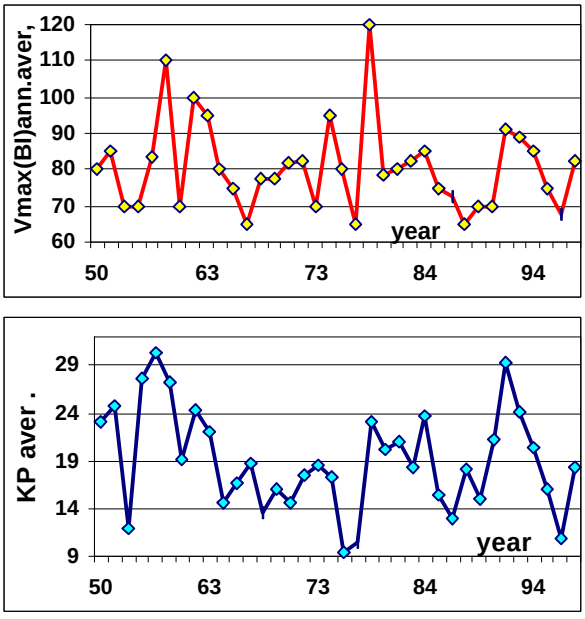

Fig. 4. Line plot of the annual averaged maximum hurricane intensity (type BI) and annual averaged 10-day mean KP index.

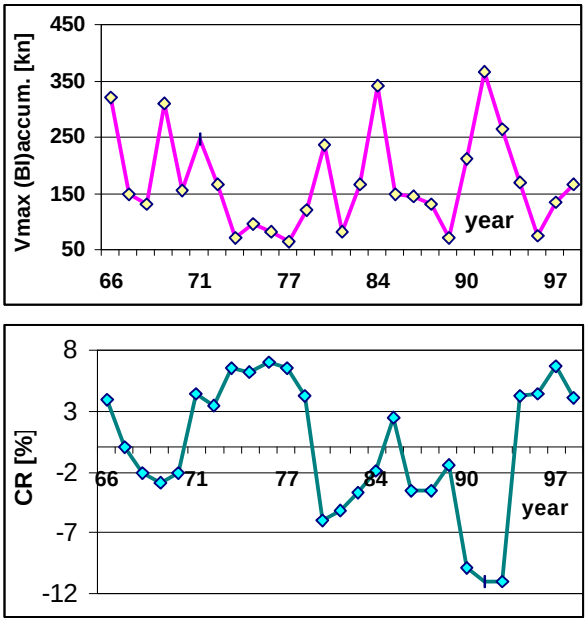

Fig. 5. Maximum hurricane intensity accumulated for all hurricanes in a season, and CR intensity averaged over the days before the hurricane and for all hurricanes in a season.

the hurricane and its path length. All analyses pointed toward a negligible connection between the hurricane characteristics (Vmax, D, and L) and the basic geophysical, heliophysical and space parameters. The lone exception is a significant positive correlation between hurricane a Vmax and the KP index. The relationship appears for the baroclinically-initiated hurricanes only.

Intensification factors for baroclinically-initiated hurricanes are least understood. A possible triggering mechanism, related to the ionization of the upper extent of the hurricane vortex that leads to additional latent heat release and subsequent warming of the core region of the storm is suggested (e.g. Tinsley 2000). Central core warming lowers the surface air pressure underneath the hurricane, which leads to its intensification.

The CR intensity and hence the CR ionizing factor changes are very limited and their direct influence (if it exists) could be hardly noticed. On the other hand the high negative correlation between the CR and yearly-accumulated hurricane type BI total energy **(Fig. 5.)** shows, that the solar corpuscular fluxes, deflecting the cosmic rays, could provide an extra ionization, which could enhance the hurricane intensification.

So, because of their fast response to solar activity variations, the CR intensity changes could provide some preliminary information for the degree of upper atmosphere ionization.

As was originally suggested from one of the authors(J.E.), the hurricanes, which could be influenced the most from all these processes, are those of type BI. Through all our computations, that was noticed persistently.

6. Acknowledgements.

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