# Preliminary Study of the 400-Year Geomagnetic Cutoff Rigidity Changes, Cosmic Rays and Possible Climate Changes

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## Abstract

The studies of Friis-Christensen and Svensmark reported a variation of 3–4% in the global cloud cover between 1980 and 1995 that appeared to be correlated with the change in galactic cosmic radiation flux over the solar cycle. Using world grids of vertical cutoff rigidities calculated over a 400-year interval and assuming constant solar modulation over that period, we find that the cosmic ray flux over the globe has increased by 18 percent. This change is equivalent to the cosmic ray flux at high latitude locations over a solar cycle. We also find that the change in the cosmic ray flux over the 400-year interval is not uniformly distributed. We suggest that the long-term change in the cosmic radiation impinging at the top of the atmosphere at specific locations on the globe should be considered in studies of possible relationships between cosmic radiation and climate.

## 1. Introduction

The earth's climate has been continually changing. Any change in the average energy from outside the magnetosphere that ultimately reaches the earth's atmosphere may affect the climate. This includes, but is not limited to, solar energy inputs in its various forms and cosmic radiation. Over the years a number of correlations between solar activity variations and climate changes have been reported; however, there has been a lack of plausible physical mechanisms to account for these correlations.

In the search for a physical mechanism that could account for reported correlations between solar associated parameters and climate, Friis-Christensen and Svensmark (1997) and Svensmark and Friis-Christensen (1997) found that an observed variation of 3–4% of the global cloud cover between 1980 and 1995 appeared to be correlated with the change in galactic cosmic radiation flux over the solar cycle. In more recent work, Marsh and Svensmark (2000) suggest that a reduction in the cosmic radiation flux results in a reduction of the low cloud cover, the low clouds having a strong cooling effect on the climate. They suggest that a decrease in the cosmic radiation flux over the past century accounted for a significant fraction of the observed global warming over this period.

pp. 4205–4208 

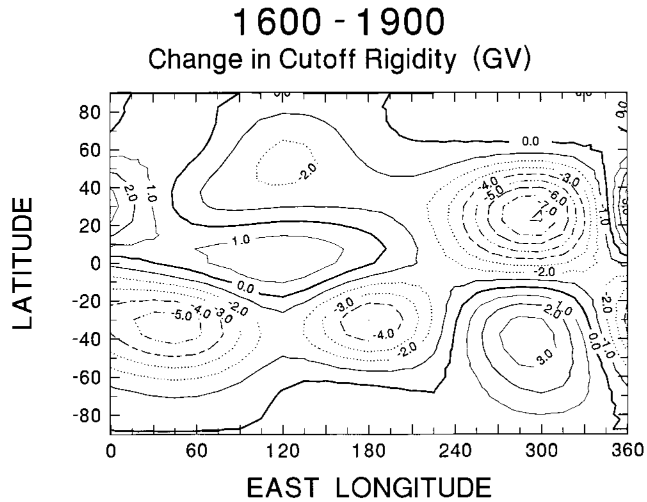


**Fig. 1.** Contours of the change in vertical cutoff rigidity values (in GV) between 1600 and 1900.

The amount of cosmic radiation reaching the top of the atmosphere is a function of the earth's geomagnetic field. Since there is a long-term evolution of the earth's magnetic field, any variation in this field may also have climatic effects (Anderson, 1992). At this point in geological time the earth's geomagnetic field is rapidly changing. While the total field is decreasing, the changes are non-uniform over the earth. In this paper we show that the amount of cosmic radiation impinging at the top of the atmosphere has a considerable variation from place to place over the past 400 years, and these variations should be considered in long-term climatic studies.

## 2. Method

Using the trajectory-tracing method (Shea et al., 1965), geomagnetic cutoff rigidities have been calculated for world grids (5 degrees in latitude and 15 degrees in longitude) using numerical geomagnetic field models appropriate for 2000, 1900, 1800, 1700 and 1600. See Smart and Shea (2003a) for specific details. Figure 1 illustrates the change in cutoff rigidity values between 1600 and 1900. The cutoff rigidities decreased over North America while increasing over Europe as the location of the dipole migrated from east to west. The cutoff rigidity also significantly decreased over Southern Africa.

We determined the cosmic radiation flux impinging at the top of the atmosphere for selected locations as follows:

1. The cosmic ray flux above the geomagnetic cutoff rigidity was calculated for selected locations for both 1600 and 1900.

**Table 1.** Vertical Cutoff Rigidities (GV) for Various Epochs

| Lat. | Long. (E) | Epoch 2000 | Epoch 1900 | Epoch 1800 | Epoch 1700 | Epoch 1600 | Change in GCR flux (1600–1900) | |
|---|---|---|---|---|---|---|---|---|
| 55 | 30 | 2.30 | 2.84 | 2.31 | 1.49 | 1.31 | −48% | Europe |
| 50 | 0 | 3.36 | 2.94 | 2.01 | 1.33 | 1.81 | −37% | Europe |
| 50 | 15 | 3.52 | 3.83 | 2.85 | 1.69 | 1.76 | −55% | Europe |
| 40 | 15 | 7.22 | 7.62 | 5.86 | 3.98 | 3.97 | −58% | Europe |
| 45 | 285 | 1.45 | 1.20 | 1.52 | 2.36 | 4.14 | +214% | N. Amer. |
| 40 | 255 | 2.55 | 3.18 | 4.08 | 4.88 | 5.89 | +118% | N. Amer. |
| 20 | 255 | 8.67 | 12.02 | 14.11 | 15.05 | 16.85 | +68% | N. Amer. |
| 20 | 300 | 10.01 | 7.36 | 9.24 | 12.31 | 15.41 | +195% | N. Amer. |
| 50 | 105 | 4.25 | 4.65 | 5.08 | 5.79 | 8.60 | +132% | Asia |
| 40 | 120 | 9.25 | 9.48 | 10.24 | 11.28 | 13.88 | +76% | Asia |
| 35 | 135 | 11.79 | 11.68 | 12.40 | 13.13 | 14.39 | +37% | Japan |
| −25 | 150 | 8.56 | 9.75 | 10.41 | 11.54 | 11.35 | +25% | Australia |
| −35 | 15 | 4.40 | 5.93 | 8.41 | 11.29 | 12.19 | +178% | S. Africa |
| −35 | 300 | 8.94 | 12.07 | 13.09 | 10.84 | 8.10 | −63% | S. Amer. |

2. The difference in the flux over this 300-year period was determined and the differences expressed as a function of percentage change from 1600 until 1900.

The solar minimum spectrum of Webber was assumed to be constant over this time period, so these results are for solar minimum conditions. Long-term modulation of the cosmic ray spectrum was not included in these calculations.

## 3. Results

Vertical cutoff rigidity values for selected locations (approximate geographic areas are identified) and for four epochs of the magnetic field are listed in Table 1. The final column of numbers presents the change in cosmic ray flux over the 300-year period from 1600 to 1900 assuming solar minimum conditions. This 300-year period was selected since it was prior to any major greenhouse effects on temperatures.

## 4. Discussion and Conclusion

The strength of the earth's magnetic dipole has decreased significantly between 1600 and the present time. Smart and Shea (2003b) have estimated a globally averaged increase in the cosmic ray flux of ∼!8% over this 400-year period.

The vertical cutoff rigidity values and changes in the galactic cosmic radiation in Table 1 reflect major changes at individual locations over a 300-year period. These changes are not uniform. There are also locations (e.g. 55N, 30E; 20N, 300E; 35S, 300E) where the 300-year trend reverses between 1900 and 2000.

The derivation of a physical relationship between galactic cosmic radiation and cloud cover (and hence climate) is complex. There are two sources of climatology records: long-term measurements for individual locations and approximations derived from these measurements to estimate global trends. While reliable cloud cover data exist for some individual locations, full global coverage data are available only since 1983. Kristjánsson et al. (2003) suggest that correlation coefficients between solar-terrestrial parameters such as cosmic radiation and/or solar irradiance and climatic parameters computed at different geographical locations would be more meaningful than global correlations.

We suggest that investigations of a possible relation between galactic cosmic radiation and climate for specific areas of the world where reliable climatic data are available should include the changes in the cosmic radiation flux at that particular location over the time period under investigation. This does not have to be done on a point by point basis, but can be done over a regional basis such as northern Europe.

In using the more recent global cloud cover data, it is now possible, using world grids of vertical cutoff rigidity values calculated for 1980 and 2000, to estimate the changes in cosmic radiation over the entire globe during that period or over a specific region of the globe. There are some regions of the world where the vertical cutoff rigidity is changing by as much as 1% per year (Shea and Smart, 1990) and the changes in galactic cosmic radiation over these regions over the 20-year period may be sufficient to provide meaningful insight to the cosmic radiation/cloud cover hypothesis.

## 5. Acknowledgments

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