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Full Length Research Paper

Can we use the aa geomagnetic activity index to predict partially the variability in global mean temperatures?

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Data for geomagnetic activity index aa and solar sunspot number Rz for 1868-2004 were subjected to correlation analysis with the global surface temperature (GST). The annual-means GT show that it had two warming phases and one cooling period. Observations of the Earth's near-surface temperature showed a global-mean temperature increase of approximately 1.1° C since 1877, occurred from 1887 to 1940 and from 1970 to the 1998. The temperature change over the past 35 years (1970-2004) is unlikely to be entirely due to internal climate variability. Attribution of the warming early in the century has proved more elusive. The correlation analysis between the variation of global temperature and both aa geomagnetics and solar activity are +0.5 ± 0.05, for any lag or lead, indicating a significant role in such variation. All graphs have illustrated strong correlations between the solar activity and geomagnetics and surface global temperature. Our results do not, by any means, rule out the existence of important links between solar activity and terrestrial climate. Our results displayed that the present changes in aa geomagnetics may reflect partially some future changes in the global surface temperatures.

Key words: Geomagnetic induction, Atmospheric sciences, Climatology, Climate and interannual variability.

INTRODUCTION

Global warming is a term used to describe an increase over time of the average temperature of the Earth's atmosphere and oceans. It plays an important role in the ongoing public debate concerning global warming and the risk of man-made climate change. Over the past century or so, the global (land and sea) temperature has increased by approximately 0.6 ± 0.2°C. Temperatures in the lower troposphere have increased between 0.08°C and 0.22°C per decade. Since 1979, the average temperature rise was not linear, but had rises and falls superimposed on it due to natural variability (private communications, http://www.grida.no/climate/ipcc_tar/wg1/).

Lassen and Friis-Christensen (1995) have demonstrated a strong correlation between solar cycle lengths and Northern Hemisphere temperatures over the period 1860- 1990. Following studies (Lassen and Friis-Christensen, 2000; Laut and Gundermann, 2000 a;b; Thejll and Lassen , 2000) have taken an update data of the same results.

Recently, several researchers have applied correlation analysis to climate-related time series (e.g., Laut, 2003; Rahmstorf et al., 2004). Other (Shaviv and Veizer, 2003) reported that fluctuations in cosmic ray flux reaching the Earth can explain 66% of the temperature variance over the past 520 my, and that the sensitivity of climate to a double of CO_2 was less than that previously estimated. Belov et al. (2005) presented a new method of prediction for the expected part of global climate change by forecasting of galactic cosmic ray intensity (GCRI) time variation in near future based on solar magnetic field data. Moreover, they determined parameters of convection-diffusion and drift mechanisms. The method gave possibility to make prediction of expected part of global climate change, caused by long-term cosmic ray intensity variation.

Svensmark and Friis-Christensen (1997) published an article showing a strong correlation of total cloud cover with the intensity of galactic cosmic rays as measured at

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Climax, Colorado. Svensmark (1998) updated the article.
A new hypothesis was presented (Marsh and Svensmark,

2000a;b) displaying that the low cloud cover, rather than the total cloud cover, exhibited a strong correlation with galactic cosmic ray intensity, here represented by data from the Peruvian station Huancayo. Kristjánsson et al. (2000, 2002) have compared the correlation of low cloud cover with total solar irradiance and GCRI, respectively and they found that the correlation coefficient with total solar irradiance was by far the highest ($r = 0.80$ vs. $r = 0.47$).

Global warming theories attempted to account for the rise in average global temperatures since the late 19th century (0.6 ± 0.2°C) and assess the extent to which the effects are due to human causes. The most common global warming theories attributed the global temperature rise to increases in the greenhouse effect caused primarily by anthropogenic (human-generated) carbon dioxide (CO2) and to possible increases in solar activity (Lassen and Friis-Christensen, 2000; Kristjánsson et al., 2002; Rohmstorf et al., 2004) . Climate models, driven by estimates of increasing CO2 and to a lesser extent by generally decreasing sulfate aerosols, predict that temperatures will increase (with a range of 1.4°C to 5.8°C for the years between 1990 and 2100). Climate commitment studies predict that even if levels of greenhouse gases and solar activity were to remain constant, the global climate is committed to 0.5°C of warming over the next one hundred years due to the lag in warming caused by the oceans. These hypotheses play continuously an important role in the scientific, as well as in the public debates about the possibility or reality of a man made global climate change.

Near -Earth variations in the solar wind, measured by the aa geomagnetic activity index, have displayed good correlations with global temperature (Landscheidt, 2000). Lockwood et al. (1999) found that the total magnetic flux, leaving the Sun and driven by the solar wind, has risen by a factor 2.3 since 1901, leading to the global temperature increased of 0.5º C. In addition, the solar energetic eruptions, which dragged out or/and organized by the observed variations in the solar wind, are closely correlated with the near -Earth environment (El-Borie, 2003a;b). Comparison of the aa geomagnetic with the solar wind, post-1965, showed a fairly good match, indicating that the aa variations were mostly due to similar variations in the solar wind, which must have their origin in solar physical processes (Feynman, 1982; Kane, 1997; El-Borie, 2003a;b).

In the present work, we investigate the possible role of some solar parameters in climate variability of global temperature. Indices of solar disturbance, measure the near-Earth variations in the solar wind, have been studied. Here, we present a correlative study of the possible contributions for the two components that may be closely associated with the climate, throughout the last 137 years (1868-2004).

RESULTS AND DISCUSSION

The used data are the global surface temperature measurements (private communications, http://data.giss.nasa.gov/gistemp/tabledata/) provided by the U.S. National Aeronautic and Space Administration’s Goddard Institute for Space Studies GISS, from 1868 to 2004. The ‘surface record’ comprises the combined average of thousands of thermometers in every country, worldwide, recording temperatures in standard, white, louvered boxes called Stevenson Screens. The boxes mounted one meter above the ground. Temperature measurements of the marine atmosphere usually are performed from Stevenson Screens mounted near the ship's bridge, while sea surface temperature measurement utilizes intake pipes in the ship's hull. Satellite measurements of the sea surface temperature over the ocean, have been recently performed. Furthermore, we have used data of the aa geomagnetic activity index and sunspot numbers Rz, provided by the National Geophysical and Solar-Terrestrial Data Center (private communications, http://www.ngdc.noaa.gov/stp/GEOMAG/aastar.shtml), of the same period.

Figure 1a displays the yearly means surface temperature (bar lines) with the five-year running mean (solid curve) during the period 1868-2004. Plot 1b shows the aa indices, for comparison, which displays considerable variation with the time series. The upper plot illustrates substantial year-to-year variability of global temperature, as well as, coherent long-term change. We notice that, the global temperature had a tendency to increase almost steadily for more than hundred- year ago, around the year 1880. The Earth’s environment has been becoming warmer since 1880. We can see that the annual mean temperature showed a sustained warming of about +0.45°C from 1890 to 1940 (+0.09°C/decade). An important feature is that the temperature rose sharply by about 0.4ºC between 1910 and 1940. The concentration of the man-made gases (greenhouse gases) increased after 1940 and therefore, we cannot consider the man-made was the cause of the 0.4ºC warming that occurred earlier years. Then there was a cooling of about -0.22°C from 1940 to around 1970 (~ -0.07°C/decade), followed by a second phase of warming of about +0.62°C from 1975 to 2004 (~ +0.21°C/decade).

Of particular interest with the recent years, the second phase of warming, from around 1970 to 2004. The increase in GST was faster and smoother than in the first warming region. The 2004 meteorological year was the fourth warmest year (yr) over the record. The warmest temperature occurred in 1998 (+0.56°C), while the second and third warmest years were 2002 (+0.54°C) and 2003 (+0.52°C), respectively. There has been a strong warming trend over the past 40 yrs. We should note that, the GST in 1998 was associated with one of

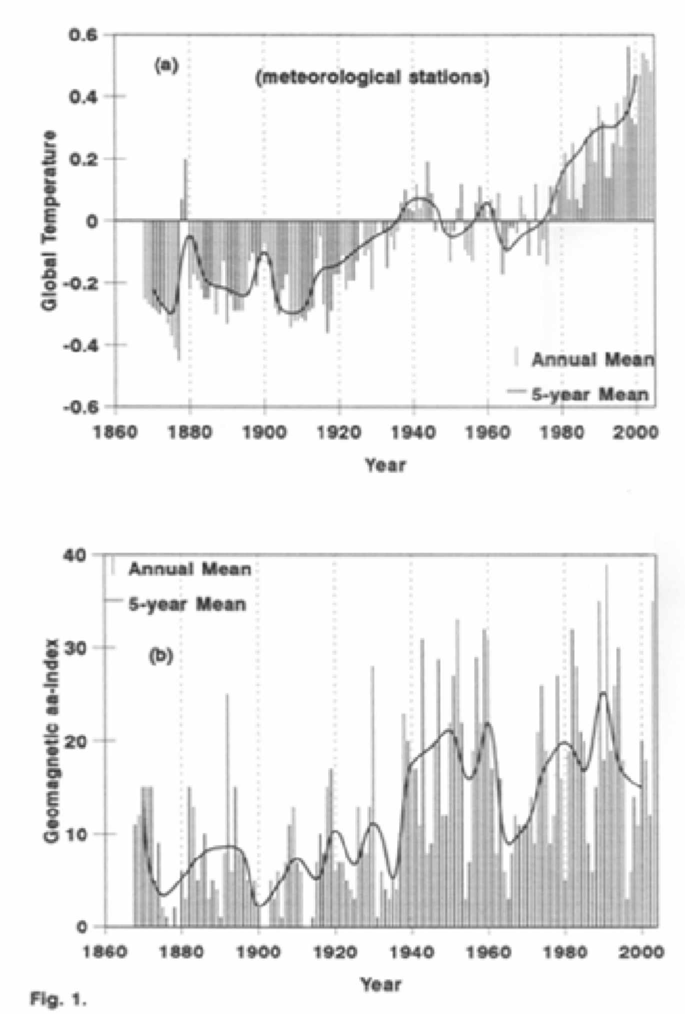

Figure 1. (a) Annual means of global temperature (bar lines) with the five- year running averages (solid curve) for 137 years (1868-2004). (b) Comparison of the aa geomagnetic indices with the global temperatures (GT).

the strongest ElNinos in recent centuries. In contrast, the coolest annual mean temperature was -0.44°C in 1877 and increased to the highest one in 1998. Temperatures have increased, and reflected a warming of approximately 0.08°C/decade since 1877.

Plot 1b dispays the yearly and 5-year aa running means. Some periodic structures are seen. The thick line, in-between, is centered for five years apart. For a comparison between the two plots, we notice the followings:-

1. During the period 1880-1940 (1^{st} warming region), the aa magnitudes are low or moderate. In addition, there are only two significant peaks in 1892 and 1930. Concomitantly to these peaks, global temperatures showed a sustained warming of +0.19°C just after the first peak till the year of 1899. In addition, the temperatures increased post-the second peak to the year of 1937. These increases were observed later by 6-7 years. The two considered peaks occurred slightly before the solar activity cycle 13 (1889-1901) and in the declining phase of cycle 16 (1923-1933), respectively. Generally, the aa maxima had an irregular pattern and two aa maxima were observed (double peaked modulations) near the maximum solar activity period (e.g., Kane, 1997; El-Borie2001a;b).

2. During the period 1940-1970, the global cooling period, the averages of aa showed great fluctuations. These fluctuations in aa are due to corresponding variations in the solar activities. The maximum solar activity decreased from cycle 11 to cycle 14 (1867-1913), increased thereafter up to cycle 19 (from 1913-1964), decreased considerable in cycle 20 (1964-1976), rose to moderate levels in cycles 21, 22 (1976-1996), and then decreased again in cycle 23 (1996-2004).

3. During the period 1970-2004, the second warming portion, the aa geomagnetic magnitudes values have greatly increased than the two previous periods. The largest peak, over the considered period, was in 1991 and the warmest year was 1998, of 7-yr apart. The second and third largest peaks were in 2003 and 1994, respectively. For comparison, the separation-time between the second warmest year in 2002 and the third greatest geomagnetics is 8yr. .

Figure 2 shows the scatter plots of the 5-year means (up) and the smoothed yearly means (down) of the global temperature with the geomagnetic aa index (left scales) and the sunspot number (right scales). The straight-line fit indicates a close correlation between aa and GT, the correlation coefficient is = +0.7.The corresponding correlation between Rz and temperature is = +0.55. Landscheidt (2000) declared that the temperature should lag the aa, as well as, he found that the correlation reaches a maximum when temperature lags by 6 years. Since there is a linear relationships between GT and both aa index and Rz, the 185 % rise in the Sun's geomagnetic disturbances since 1901 corresponds to a rise in the global temperature. The increase of 0.32°C potentially accounts for nearly half of the change in the Earth's global over the same period. In addition, on average, the increase in Rz was 6.3/decade since 1900, which reflected a rise of +0.03°C in the mean temperature. El-Borie (2003a;b) displayed that the increase in solar activity had meteorological effects within days after solar eruptions, which generate high speed solar wind streams (HSSWS).

It would be interesting to check the correlations of both aa and Rz, with GT. Results of the cross correlation analysis are shown in Figure 3. Plot 3a shows the cross-correlation magnitudes of the 3-yr running mean of GT

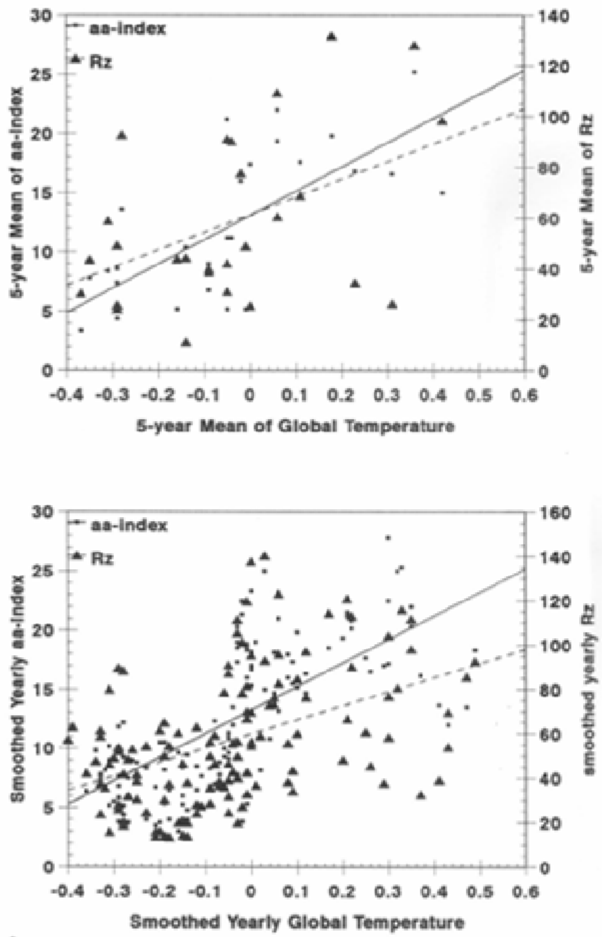

Fig. 2.

Figure 2. Scatter plots of the aa-index (dashed lines) and sunspot numbers (solid lines) with GT. The top panel (a) is for the 5-yr means, while the bottom (b) is for the smoothed yearly measurements. Regression coefficients have been computed.

with both Rz and aa, for the period 1868-1930. The next two plots are for the two successive intervals 1930-1970 and 1970-2004. The correlation of GT and Rz displayed by dashed curve, while the correlation between GT and aa displayed by the solid curve. The 12-yr lag time ( ) is considered. For these correlations, is the lag, usually recommended to be ~ 30 % of the data length. The =0 means the both data sets are in time (zero lag). For individual correlation, we can see that:

1. For the period 1868-1930, which corresponds to the first-warming region in Figure1a, the largest peaks are at 6-7 yr lag with magnitudes of ~ +0.5 ± 0.05 for the correlation aa-GT, and ~ +0.4 ± 0.03 for Rz-GT. At zero lag, a negative value (~ -0.25 ± 0.03) has been observed. The relationships between GT and both aa and Rz are slightly different and not equally strong, at least in this

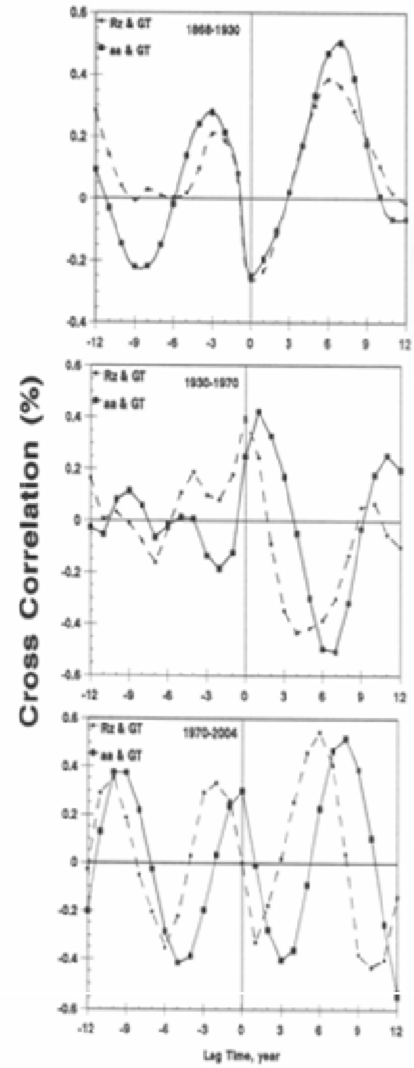

Fig. 3.

Figure 3. The cross-correlation of the 3-yr running averages of GT with both Rz and aa for the three selected periods, 1868-1930, 1930-1970, and 1970-2004. The lag time of ±12-yr has been considered.

period.

2. In plot 3b, each correlation has significant magnitude, the largest at 0-1 yr lag. In contrast, the largest negative amplitude is ~ -0.4 ± 0.03, at lag time of 4-7 yr. The covariance between the two curves may be due to the fact that aa and sunspot numbers are both parameters connected to solar activity, and that a causal relationship with solar irradiance automatically will imply a certain degree of correlation with geomagnetics.

3. The plot 3c illustrates the correlations of aa-GT and Rz-GT in recent years. The curves display that the peaks

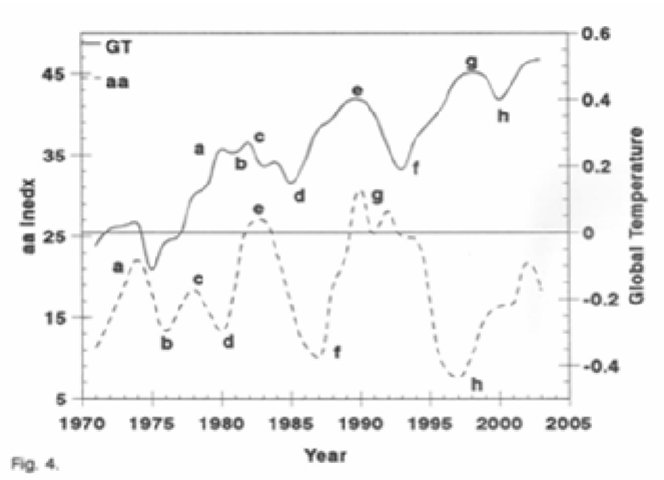

Figure 4. Comparison of the recent years of global temperature (solid line) with the aa-index of geomagnetics (dash line).

of GT lag by 5-7 yr about the peaks of Rz or aa. In addition, the two curves have similar behavior (both qualitatively and quantitatively) with 1-2 yr lag between them, indicating that both solar parameters have a great role over GT. Almost, every aa-GT peak is seen in the Rz-GT correlation (the correlation is 50%), but with a lag time. At zero time, a remarkable magnitude (~ 0.3 ± 0.02) is observed, then both magnitudes decreased to lower values at 1-3 yr.

The comparison between the three plots led us to conclude that, during the cooling part in GST, the GT correlated well with both aa and Rz at 0-1 yr lag, while during the two warming parts, the GST showed significant and larger correlations at later years. The global temperature displayed a remarkable correlation at zero lag time for the two warming plots (± 0.25%). Generally, the plots displayed that the significant role of Rz on GT precedes the role of aa by 1-2 yr. In addition, nearly all fluctuations (or variations) in GT seem to be partially (~ 50 %) caused by similar aa fluctuations, and preceded by few yrs. In recent years (1970-2004), the observed peaks of Rz and aa in 1989 and 1991 could explain the lag of high temperatures in 1995 and 1998, respectively. Furthermore, just after 1959 the geomagnetic aa data showed a steep decline, followed by falling temperatures in 1964 -66. On the other side, the aa index has risen by a factor 3.2 during the period 1988-1995. Concomitantly, global temperature has increased by 0.31°C during the period 1995- 2002. Thus, the relationships of GT-aa and GT-Rz were not equally strong for all the selected periods, allowing for the possibility of some other interfering factors.

Figure 4 shows the three-year running averages of aa index (dash curve, left scale) and the recent measures of global temperature (solid curve, right scale) from 1970 to 2004, the second warming phase. The original data have used without any offset. It has been noticed that temperature lags aa by 5-7 yr. The connection between the leading aa extrema and the following temperature extrema is labeled by letters from a to h. On first sight the steep rise of GST after 1975 (see solid curve) seems to correlate well with a corresponding steep rise in aa geomagnetic activity. The lag time varies from 5 to 7 yr. The aa curve leads the GT measures. Both curves from d to h show how the variations of global temperature depend on the aa magnitudes. A remarkable variation (decrease or increase) in temperature (~ ± 0.25°C) followed a noticeable variation in the geomagnetics. At the two points d and e, the magnitude of increasing in temperature was ~ 0.2°C, while the rate of increasing in aa was 86 %, above the observed aa magnitude. In addition, the two points e and f reflected a decease in temperature due to a decrease in geomagnetic aa, with lag 6-yr. Around 1990, the aa measured the largest value ever, labeled by g. The connection between aa and global temperature pointed that the corresponding temperature has occurred in 1998, with lag ~ 8 yrs. Around 1997, the aa reached the minimum value during the considered period. After that, the aa increased slowly to a moderate values (or reasonable) until 2003. Accordingly, the future temperature can be predicted from the present aa geomagnetic measures, by allowing the lag time of ~ 6-7 yr. We think, the explanation of that is, the excess of aa geomagnetics led to excess solar energy which stored and accumulated for few future years in the near-Earth system. This process may take few years (5-7 yr) to influence on the global temperature.

Plot 5b displays the linear correlation coefficient R (t) for the yearly mean GT with each of the aa-index (dashed curve) and solar activity Rz (solid curve). In this analysis, data were subjected to running five-point (plot 5a). Then, we used a time series of width T and centered at time t, where t-T/2 t t+T/2. We have performed the analysis for the running correlation coefficient for data within this window, which was T = 12 of the particular selected data. This value was chosen to match the contradictory requirements: (1) it is equal the length of nearly one solar activity cycle; (2) uncertainties of the calculated R (t) are smaller for long T; and (3) T should be small in order to reveal the fine temporal structure of that function (Usoskin et al., 1998). The record of values mean reduced to independent data (from 1873 to 1998). The values |R(t)| = 1 represent the total coincidence of the data sets. R(t) = 0, no coincidence, and the sign of R (t) is the same as the sign of a slope of sensitivity relation between data sets.

The graph 5b shows the running correlation of GT with aa and Rz values. The studied period has been divided, according to the state of GST, into three main periods (1873-1930; 1931-1970, and 1971-1998). The considered epochs have been displayed in upper panel by vertical dashed lines. The major features are:

1. During the period 1873-1930, there are no positive correlations between the mean temperatures and both aa and Rz till the year 1925 (note the plot 3a at zero lag time). Small measures of aa (< 12 nT) and Rz (< 100) showed negative correlations with temperature, at all. The behavior of the two curves is nearly identical. Strong negative correlations |R (t) 0.5-0.7| are observed for the periods 1882-83; 1896-97; 1911-12; and 1917-19. Note that, the periods of 1882-83 and 1917-19 are the maxima of solar cycles 12 and 15, respectively. Also, the period 1911-12 is around minimum solar cycle 14. On the other hand, some values reflected no correlation |R (t) ± 0.1|, which are 1873-80, 1885-87, 1900-02, 1906-08, 1914-16, and 1920-24. Thus, the running coefficients for the late years of the century 18th and the earlier years of the century 19th (~ 6 decades) displayed only negative remarkable role of solar activity or/and aa geomagnetic in temperature change. The work of Tett et al. (1999) showed the same results in the second half of the century.

2. During the period 1931-1970, which corresponds to the cooling years in GST, the behavior of both curves is different. The two considered parameters have a dominant role in temperature change. There is an observable positive correlation (between Rz and GT) with magnitude R (t) +0.75 in the two periods 1934-38 and 1956-61 (Rz >100). Lesser magnitude of anti-correlation (|R(t)| = 0.6) around the years 1943-48. Only the years from 1940 to 1950 reflected anticorrelation between Rz and GT, otherwise reflected positive magnitudes. Note that, there are positive correlations at zero lag time in plot 3b and the magnitudes were +0.4. On the other hand, the correlation between aa and global temperature showed positive values with high magnitude |R(t)=0.6| throughout the period 1947-57, otherwise the magnitudes are smaller. Therefore, the aa index and the sunspot number may be played, direct or indirect, a great role in global cooling temperature throughout four decades from 1931 to 1970.

3. During the period 1971-1998, the correlation between Rz and temperature persisted positively. The third peak (two peaks observed during the previous period) in 1974-80, followed another one with less magnitude (1985-87). Then, the running correlation coefficients gradually decreased with time to negative values at 1994-95. Furthermore, the relation between aa and temperature displayed five strong anticorrelations of reasonable magnitude.

Therefore, the variability of the correlation waves is different for the two parameters. Generally, the correlation coefficients of aa-GT maintained with negative magnitudes during the two warming phases of GST, as well as, a positive correlation during the cooling phase. So, the decreasing in aa coincides with increasing in GT when the both data are in time (without lag). Note the negative correlations between aa and GST, in plots 3a and 3c, both at 0-1 yr lag. The correlation between them is positive only at a few yrs lag. So, the sensitivity of global temperature to aa geomagnetics is significant and may be real. These results could indicate that geomagnetic disturbances, driven by the solar wind, may influence global temperature, but the physical mechanism may be related to variations in solar irradiance rather than to aa. The temperature variations in the stratosphere, caused by variations in solar irradiance at ultraviolet wavelengths, are considerably larger than the variations in the visible domain and in turn give rise to dynamics response in the troposphere that can influence surface temperature (Udelhofen and Cess, 2001) . However, further work is necessary to confirm their roles.

CONCLUSIONS

The scientific and public discussions about the influence of the solar radiation on global warming are still ongoing. The extent of human impact on climate remains a highly complex scientific matter. It is obvious that the man-made gases (e.g., the concentration of carbon dioxide in the atmosphere was never as high during the last thousand years as it is today) is an important factor affecting the Earth’s surface temperature, but it is not the only one. The solar influence, the variability in the ultraviolet radiation affects the ozone in the upper atmosphere and thus may lead to a temperature change, the solar variability also modulates the cosmic rays, which in turn may affect the cloud cover and thus leads to a temperature change. Since the pattern of the recent observed warming agrees better with the greenhouse warming pattern than with the solar output response, it is likely that one of these factors is the increase of the atmospheric greenhouse gas concentration.

The global temperature variability showed a strong warming trend over the past 40 yrs. The increase in GST for the recent years (from 1970 to 2004) was faster and smoother than in the first warming region (1868-1930). The warmest temperature occurred in 1998 (+0.56°C), while the second and third warmest years were 2002 (+0.54°C) and 2003 (+0.52°C), respectively. The 2004 meteorological year was the fourth warmest year over the record. In contrast, remarkable strong variations in aa magnitudes were observed earlier by 6-7 years.

The annual mean temperature showed a sustained warming (Figure 1) of about +0.09°C/decade for the 1890-1940 epoch. Then, there was a cooling phase with ~ -0.07°C/decade during the period 1940-1970, followed by a second phase of warming of ~ +0.21°C/decade from

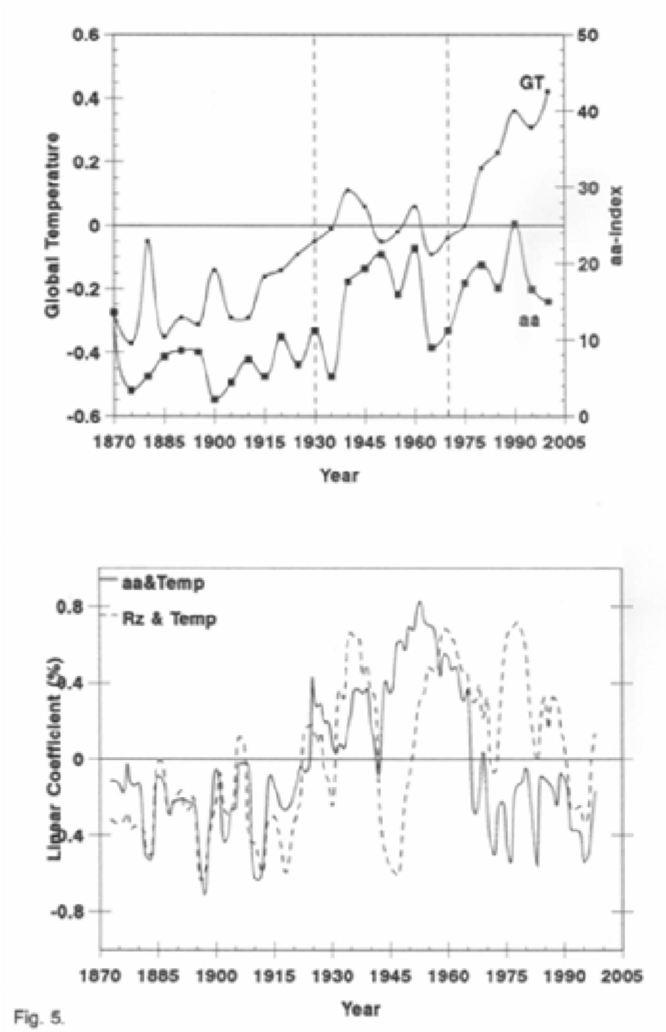

Figure 5. (a) The 5-year running averages of GT and aa-index. (b) Linear correlation coefficients R(t) for the yearly means of GT with aa-index (dashed line) and solar activity index Rz (solid line). The time series t is centered at t-T/2 t t+T/2.

1975 to 2004. In plot 3b, the GT correlated well with both aa and Rz at 0-1 yr lag, while during the two warming regions (plots 3a &3c), the GST showed significant correlations at later yrs. Nearly all fluctuations (or variations) in GT seem to be partially (~ 50 %) caused by similar fluctuations, preceded by few yrs, in the geomagnetics and activity parameters. In the recent years (1970 on onwards), the observed peaks of Rz and aa in 1989 and 1991could explain the high global temperatures in 1995 and 1998, respectively.

The leading aa extrema and the following temperature extrema are correlated well (Figure 4). The aa curve precedes the GT temperature by 5-7 years. Both curves showed variations of global temperature depend on the aa magnitudes. The future global temperature changes may be partially predicted by the present aa geomagnetic measures. The excess of aa geomagnetics led to excess solar energy which stored and accumulated for few future years in the near-Earth system, leading to the global temperature variability. The running coefficients for the late years (1873-1930) displayed only negative remarkable role of solar activity or/and aa geomagnetic in global temperature change (Figure 5b). On contrast, the aa index and the sunspot number played, direct or indirect, a great role in global cooling temperature throughout four decades from 1931 to 1970. During the period 1971-1998, the correlation between Rz and temperature persisted positively. So, the sensitivity of global temperature to aa geomagnetics is significant and may be real.

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