A novel empirical relation between the aa index and sunspot numbers: theoretical considerations and applications

Kiminori Itoh[1]

[1] Inst. Env. Sci. & Technol., Yokohama Natl' Univ.

http://www.ynu.ac.jp

The geomagnetic activity indices (GMIs: e.g., the aa index) were successfully reconstructed on the basis of their novel relations with Wolf's sunspot numbers, R, for the period from 1500 AD to the present. The equation, aa(t) = A* {R(t- t1)}^0.5 + B*{R(t+ t0- t1)}^0.5, was found to hold well for each solar cycle when using appropriate frequency bands. This relation largely improves the conventional precursor method, and can give more accurate future values of R. The reconstructed GMI showed a good peak-to-peak correlation with historical records of cosmogenic isotope Be10 in ice cores. A similar correlation was found with historical temperature records for the northern and southern hemispheres. These findings underscore the importance of solar magnetic activity to global climate changes.

The recent increase in solar magnetic activity has certain effects on the earth, including large magnetic disturbances and possible global-climate effects [Lockwood et al., 1999; Parker, 1999]. Thus, it is important to clarify the temporal aspects of this solar magnetic activity. In this report, the geomagnetic activity indices (GMIs: e.g., the aa index) were successfully reconstructed on the basis of their novel relations with Wolf's sunspot numbers, R, for the period from 1500 AD to the present (Fig. 1). The estimation of Letfus [1994] was employed for R for the period before 1700AD. The following equation was found to hold well for each solar cycle when using appropriate frequency bands.

aa(t) = A*{R(t- t1)}^0.5 + B*{R(t+ t0- t1)}^0.5 (1)

Here, t0 and t1 are typically 7yr and 0.5yr, respectively. The time series of R and the aa index were divided into the following frequencies: 1) the frequency lower than 0.05/yr; 2) that between 0.05-0.2/yr; 3) that between 0.2-0.67/yr; and 4) that higher than 0.67/yr. The reconstruction of aa index was made for each frequency band, and the results were added to obtain the final result.

Equation 1 largely improves the conventional precursor method, and can give more accurate future values of R. The reconstructed aa index showed a good peak-to-peak correlation with historical records of cosmogenic isotope 10Be in ice cores. A similar correlation was found with historical temperature records for the northern and southern hemispheres [Jones et al., 1998] (Fig. 2). These findings underscore the importance of solar magnetic activity to global climate changes.

Physical basis and assumptions made for the equation above are described below. Sunspots are thought to result from the solar toroidal magnetic field, and the aa index observed during the period with small R is thought to approximately represent the solar poloidal magnetic field [Bravo and Stewart, 1994; Legrand and Simon, 1991; Simon and Legrand, 1992]. Thus, the followings can be assumed: 1) the total magnetic field, M, observed at the earth consists simply of a toroidal field-origin component MT and a poloidal field-origin component MP, that is, M = MT +MP; 2) the aa index is proportional to M. The reconstruction was difficult when R is assumed to be simply proportional to MT (or MP) although this is the conventional idea in the precursor method for predicting future R [Feynman, 1982; Kane, 1987; Letfus, 1994; Li, 1997; Wilson, 1998]. After examining several possibilities, a hypothesis that MT and MP are proportional to the square route of R (i.e., R^0.5), rather than to R, proved most effective. A possible physical interpretation of this hypothesis is as follows. Polygiannakis and Moussas [1996] suppose that R is linear to the square of the plasma current I in the sun because R corresponds well to changes in the solar constant as observed by satellites. Based on this assumption, these authors were able to effectively explain the changes in R by a Van der Pol type nonlinear oscillation. If their supposition holds, R^0.5 is linear to the plasma current I, and thus, the toroidal field MT is linear to R^0.5 because the current I generated by the solar dynamo should be proportional to the resultant magnetic field. If we consider that MP is in advance of MT for several years, we can then obtain the following equation.

aa(t) = A*{R(t)}^0.5 + B*{R(t + t0)}^0.5 (2)

The shape of the calculated aa(t) from R was very close to the observed aa index, but the former shifts to the past by several months. This phenomenon was observed for many solar cycles although the physical meaning of t1 is not clear at this stage. Thus, equation 1 was obtained by considering this time shift (t1). This equation shows good agreement with the observed aa index (cf. Fig. 1).

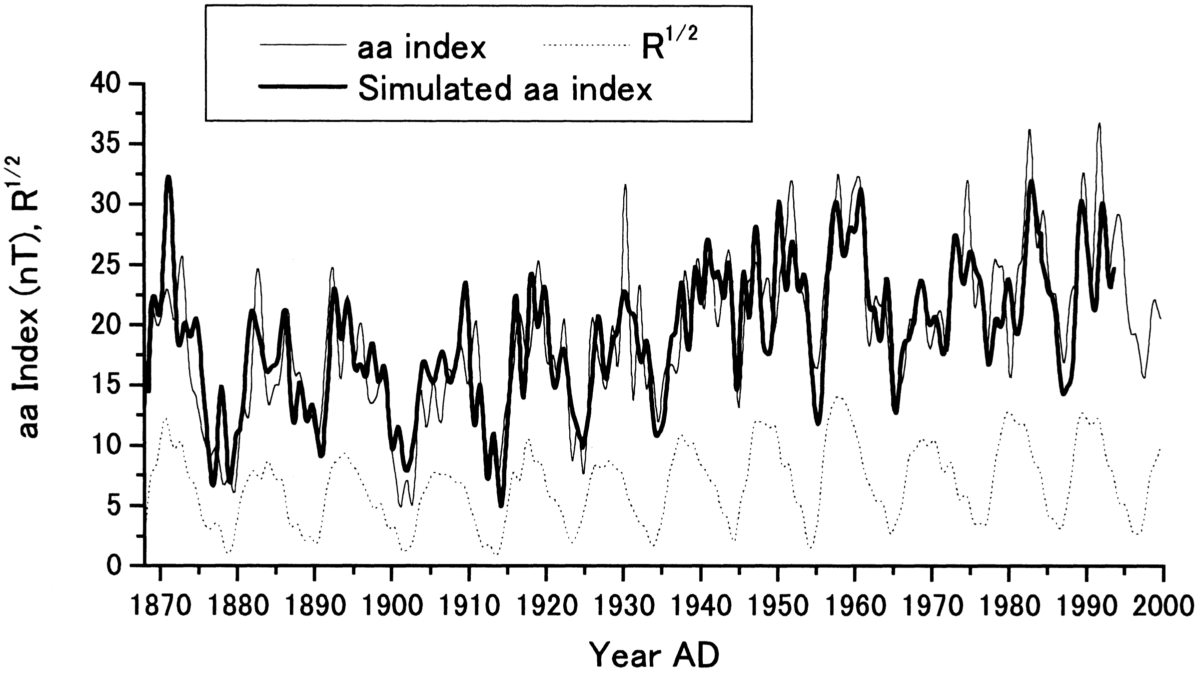

Fig.1. Reconstruction of aa index using Eq. 1.

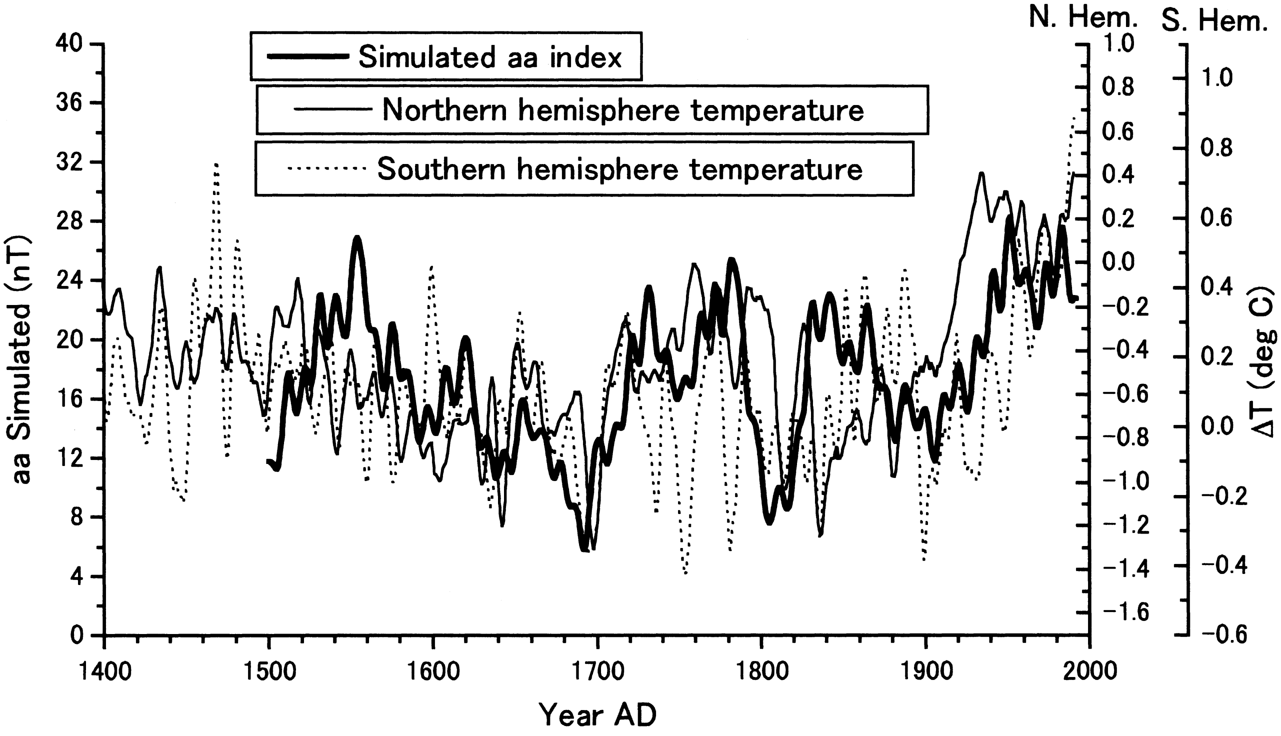

Fig.2. Relations between calculated GMI and hemispheric temperatures.
The temperature data [Jones et al., 1998] are based mainly on tree ring analyses.