CORONAL GENERAL MAGNETIC FIELD EVOLUTION
AS A NEW PARAMETER OF THE SOLAR CYCLE

HIROKAZU YOSHIMURA
Dept. of Astronomy, Faculty of Science, University of Tokyo, Tokyo, Japan

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Abstract. The magnetic field lines of the corona associated with the solar-cycle surface general magnetic field are calculated by a potential-field approximation to study the solar-cycle evolution of the geometry of the coronal field. The surface field evolution used here is the radial field evolution, predicted by a model of the solar cycle driven by the dynamo action of the global convection, and justified observationally using Mount Wilson magnetic synoptic chart data. The evolution of the calculated coronal general field is now good for comparison with observations and shows the following. (i) The field of the polar and high-altitude corona has dipolar structure in almost all phases of the solar cycle except in a short time interval around maximum phase despite the quadrupolar structure of the general magnetic field at the surface; quadrupolar field forms loop-like structure in the lower corona. The almost-dipolar structure of the polar and high-latitude corona and the loop formation of the equatorial lower corona explain the appearance of the undisturbed minimum corona observed at eclipses. (ii) The polar field lines are directed almost radially at the minimum phase, which should be responsible for polar plumes. The field lines slowly open up to participate in the loop-like structure of the equatorial lower corona, and rapidly change their structure and polarity at the maximum phase, to resume the almost radial configuration slowly. (iii) During the rapidly changing maximum phase, the field lines do not penetrate deep into the interplanetary space resulting in the absence of polar plumes and the appearance of the circular corona—the maximum corona. In this phase, the coronal field should not be approximated by a dipole field. The surface field evolution which can explain such behaviors of the corona is characteristic of the solar-cycle process dominated by the latitudinal gradient of the differential rotation. If the radial gradient dominated in the subsurface process, the coronal evolution would look quite different and would show latitudinal propagation of enhancement of activity. Although nonaxisymmetric features should be superposed on the axisymmetric general field to express the real corona, the general field can be a basic coronal field in studying long-term interaction between the convection zone and the interstellar space especially in studying the magnetic braking of the solar rotation.

1. Introduction

The photographs and drawings of the corona taken during total solar eclipses over many years have shown that the solar corona changes its form in phase with the evolution of the solar cycle. Discovered first by Rayard (1881) and Hansky (1887) as quoted by Waldmeier (1955), this phenomenon indicates that the coronal form can work as a parameter to describe the solar cycle.

This paper studies the evolution of the geometry of the coronal magnetic field lines calculated from the surface magnetic field, the evolutionary characteristics of which have been found to be important indices of the solar cycle. For the surface field we use the radial component of the general magnetic field generated by a solar-cycle model driven by the global convection (Yoshimura, 1975a) in order to study an ideal conceptual evolution of the coronal field. The basic characteristics of the evolutionary pattern of the theoretical surface field have been justified observational by the similar evolutionary patterns of the observed field using
Mount Wilson magnetic synoptic chart data (Yoshimura, 1976a, b). We compare the geometry of the field with the coronal form to study how the solar-cycle evolution of the surface field affects the dynamics of the corona to answer the question why the coronal field looks dipole-like even though the distribution of the surface general field is quadrupole-like in most phases of the solar cycle (Yoshimura, 1976a). Conversely we investigate, and try to extract, the general properties of the coronal form which can work as a parameter of the solar cycle which manifests itself in the evolution of the surface fields, studying how the coronal form is evolving in the process of the solar cycle. Considering especially that it is rather difficult to measure the polar surface magnetic field because of the tilt of solar rotation axis with respect to the orbital plane of the earth and because of the difficulty to measure the transversal component, we study the relation of the appearance of polar plumes, a characteristic feature of the corona above the poles, with the evolution of the coronal magnetic field lines. The appearance can be an important and often the only index of the polar magnetic field which plays an important role in studying the mechanism of the solar cycle. To be noted especially in this study is that the features of the general corona can also be regarded as showing that the latitudinal gradient dominates in the differential rotation in the subsurface dynamo process which has been justified before by the study of the evolution of the surface general field (Yoshimura, 1976a, b). If the radial gradient dominated in the differential rotation, the surface general field, hence the coronal general field, would show quite different behavior and would show latitudinal propagation of enhancement of coronal activity, which was not seen observationally (Gnevyshev, 1967).

2. Definition of the General Corona

The coronal eclipse photographs and drawings or the non-eclipse photographs taken by ground or space coronagraphs show that the corona has highly inhomogeneous filamentary structure. The filamentary structure has been regarded to reflect the state of the coronal magnetic field lines which originate from the solar surface (see e.g. Alfvén, 1940, 1963; de Jager, 1959, p. 269). In spite of the highly inhomogeneous structure of the corona, an overall general form of the corona can be defined and this general form should be used as a parameter of the solar cycle. In the study of the surface or inner magnetic field associated with the solar cycle (Yoshimura, 1972, 1975a, b, 1976a, b), the general field is defined as any axisymmetric component of the field. (Phenomena in a rotating spherical system such as the Sun can always be understood in terms of axisymmetric and nonaxisymmetric fields and interactions between the two.) So we define the general coronal form or field as the axisymmetric form or field of the corona.

Although streamers and other detailed structures originating from nonaxisymmetric surface features such as active regions obscure the form of the general corona, the distinction between the minimum and the maximum coronae has been