THE ROLES OF DIRECT INPUT OF ENERGY FROM THE SOLAR WIND AND UNLOADING OF STORED MAGNETOTAIL ENERGY IN DRIVING MAGNETOSPHERIC SUBSTORMS

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Abstract. This paper presents the consensus arrived at by the authors with respect to the contributions to the substorm expansive phase of direct energy input from the solar wind and from energy stored in the magnetotail which is released in a sometimes unpredictable manner. Two physical processes, neither of which can be ignored, are considered to be of importance in the dispensation of the energy input from the solar wind. One of these is the 'driven process' in which energy, supplied from the solar wind, is directly dissipated in the ionosphere with the only clearly definable delay being due to the inductance of the magnetosphere-ionosphere system. The other is the 'loading-unloading process' in which energy from the solar wind is first stored in the magnetotail and then is suddenly released to be deposited in the ionosphere as a consequence of external changes in the interplanetary medium or internal triggering processes. Although the driven process appears to be more dominant on a statistical basis in terms of solar wind-geomagnetic activity relationships, one or the other of the two above processes may dominate for any individual cases. Moreover, the two processes may operate simultaneously during a given phase of the substorm, e.g., the magnetotail may experience loading as the driven system increases in strength. Thus, in our approach, substorms are described in terms of physical processes which we infer to be operative in the magnetosphere and the terminology of the past (e.g., phases) is related to those inferred physical processes. The pattern of substorm development in response to changes in the interplanetary medium is presented for a canonical isolated substorm.

0. Prologue

Five years ago, the authors of this paper met in Münster (Federal Republic of Germany) to attempt to clear up a considerable amount of confusion surrounding the term 'substorm'. Over the previous two decades, the use of the term had moved from the area of ground-based remote sensing of the polar ionosphere to studies using in situ spacecraft observations to diagnose the physical state of the magnetosphere. Scientists in the field have heavily used perturbations in the geomagnetic field and auroral luminosity as a diagnostic tool to describe global changes in the level of the solar-terrestrial interaction. As the interest of scientists from the spacecraft community in the substorm phenomenon

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evolved, these researchers tended to rely on the early literature on the topic of substorms for their source of terminology. However, because of improved ground observations and analytical techniques, the community of ground-based researchers was developing a more detailed knowledge of substorm behaviour which led to a richer and more revealing terminology that better characterized this complex global disturbance. By 1980, substorm researchers were already attempting to clarify the relationship between historic and modern substorm terminology in the context of the improved observational database (cf. Rostoker et al., 1980).

The Münster meeting in the late summer of 1982 involved intensive discussions regarding the characteristic temporal and spatial scales of the substorm disturbance. On the basis of these discussions, the authors were unanimously of the opinion that substorm involved two characteristically different processes. These were the directly driven process in which energy from the solar wind was directly deposited in auroral ionosphere and ring current and the loading-unloading process in which energy was stored in the magnetotail for some arbitrary period of time before it was impulsively deposited in the auroral ionosphere and ring current during episodes of expansive phase activity. The details of these processes form the basis for this review and they appear in almost the identical form in which they were written by the summer of 1983. For the intervening years, this manuscript lay in abeyance because the authors, while reasonably confident about the general concept of the two processes, were divided about which of the two processes might be the dominant one. In the meantime, other researchers began using the terms directly driven and loading-unloading in the literature on a regular basis. In view of this, the authors of this paper felt it might be instructive to publish some of the original thoughts on which the concept of the two processes was based particularly since, over the ensuing five years, their opinions remained unchanged regarding the basic content of the paper. This stability of opinion suggests that the concepts discussed in this paper represent a stable phase in our expanding understanding of the substorm phenomenon.

Finally, we should note that this paper makes no direct attempt to describe the actual physical processes that go on in the regions of the magnetosphere which map to the nightside auroral oval. However, it will ultimately be necessary for the competing models which propose to explain the substorm phenomenon to take into account the overall phenomenology outlined in this paper.

1. Introduction

Some years ago Rostoker et al. (1980) presented a set of definitions and signatures for a magnetospheric substorm which consolidated the views of several active substorm researchers regarding the nomenclature for the various morphological aspects of the substorm process. At that time, the main emphasis was on the morphology of substorms, so that no effort was made to reach agreement on the physical processes involved in the determination of the morphology of substorm disturbances.

In this paper we shall document the agreement reached on the nature of some of the