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Driving of strong nightside reconnection and geomagnetic activity by polar cap flows: Application to CME shocks and possibly other situations

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ABSTRACT

Previous studies have shown that dynamic pressure impacts (e.g., shocks initiating CME storms) with southward IMF promptly lead to strong auroral nightside activity and concurrent poleward expansion (indicating strong nightside reconnection), and strong enhancements in convection and currents. Here we use a combination of ground-based ASI and radar observations to further describe this response, to address what is driving the strong activity, and to suggest similar driving in other situations. Consistent with some previous studies, we find that shock driven auroral activity and poleward expansion resembles a substorm, but starts from an already broad MLT sector without much subsequent azimuthal expansion and without classical brightening of the equatorward-most arc. We furthermore find a large enhancement of meso-scale ionospheric polar cap flows heading towards the nightside separatrix immediately after shock impact. Recent studies have shown that such enhanced flows often cross the separatrix leading to plasma sheet flow bursts, poleward boundary intensifications (PBIs), streamers, and poleward motion of the polar cap boundary from reconnection. Thus these flow enhancements, which must extend outward along field lines from the ionosphere, are an attractive candidate as the driver for the almost immediate strong auroral, current, and reconnection activity resulting from shock impact. We also discuss and present some evidence that this phenomenon may be more general, leading to similar oval responses without a shock impact, including during and following the expansion phase of some substorms. These suggestions could lead to some possibly fundamental questions, such as when do polar cap convection enhancements lead to a substorm growth phase versus leading directly to strong polar expansion of, and strong activity along, the auroral oval field line region?

1. Introduction

Abrupt enhancements of solar wind dynamic pressure (P_{dyn}), such as the shocks that initiate coronal mass ejection (CME) storms, cause dramatic effects when they occur under southward interplanetary magnetic field (IMF) conditions. They drive nearly immediately strong auroral activity, poleward expansion of the auroral oval that can reach as much as 10° in latitude, and strong enhancement in global convection, ionospheric currents, and Region 1 and Region 2 field-aligned currents (Boudouridis, 2003; Lyons et al., 2016; Zesta et al., 2000). The rapid poleward expansion of the nightside auroral oval implies strong nightside reconnection in the presence of a nearly simultaneous increase in the strength of convection.

The nightside auroral activity resembles a substorm, but initiates over a substantially broader range of MLT without much subsequent azimuthal expansion as poleward expansion occurs over a broad

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longitudinal range (Chua et al., 2001; Lyons et al., 2000; Zesta et al., 2000). These and other features, such as the lack of brightening of an equatorward arc, have led to the suggestion that the disturbance is different from substorms (Liou et al., 2003; Yue et al., 2013). However, other studies have indicated that the disturbance may be a substorm (Kokubun et al., 1977; Lyons, 2005; Zhou and Tsurutani, 2001), and dipolarizations as occur during substorms are seen at geosynchronous orbit in response to solar wind dynamic pressure impacts on the magnetosphere (Lee et al., 2005; Lee and Lyons, 2004).

In this paper, we describe the dramatic nightside response using modern ground-based all-sky imager (ASI), radar, and low-altitude spacecraft observational capabilities, and we address what is driving the strong auroral, current, and reconnection activity. We take particular advantage of the 17 March 2013 storm, a CME-driven event initiated by a shock that impacted the magnetosphere at 06 UT (Baker et al., 2014). There has been much interest in ring current particle injections (e.g., Gkioulidou et al., 2014) and radiation belt electrons (Hudson et al., 2015; Li et al., 2014, 2015) for this event. Of importance for the current study is the excellent radar and auroral observation coverage at times just before and just after the shock impact (Lyons et al., 2016; hereafter referred to as Paper 1), allowing for excellent evaluation of the effects of the shock. Consistent with some previous studies, we find that the onset of the shock-driven activity appears to be very different from the onset of a substorm. However, we find that the activity following shock impact appears to be driven by enhancements of meso-scale flows along polar-cap field lines, and this has important similarities to what has been suggested to drive prolonged activity during the expansion phase of some substorms. This, and additional evidence we present here, suggest that the driving of activity we show here may apply more generally than just to the impact of P_{dyn} enhancements.

2. Observations

Observations for the magnetic storm on 17 March 2013 in Paper 1 show that the shock impact with concurrent southward IMF immediately drove dramatic poleward expansion of the poleward boundary of the auroral oval (implying strong nightside reconnection), strong auroral activity, and strong penetrating mid-latitude convection and ionospheric and field-aligned currents. Fig. 1 shows, from top to bottom, the WIND solar wind dynamic pressure P_{dyn}, the OMNI interplanetary magnetic field (IMF) as propagated to the dayside magnetopause (both of the above time shifted to give the correct shock impact time), the SuperMAG (Gjerloev, 2012) ground magnetometer upper U and lower L auroral magnetic index, and the SuperMAG ring current index for all MLT and

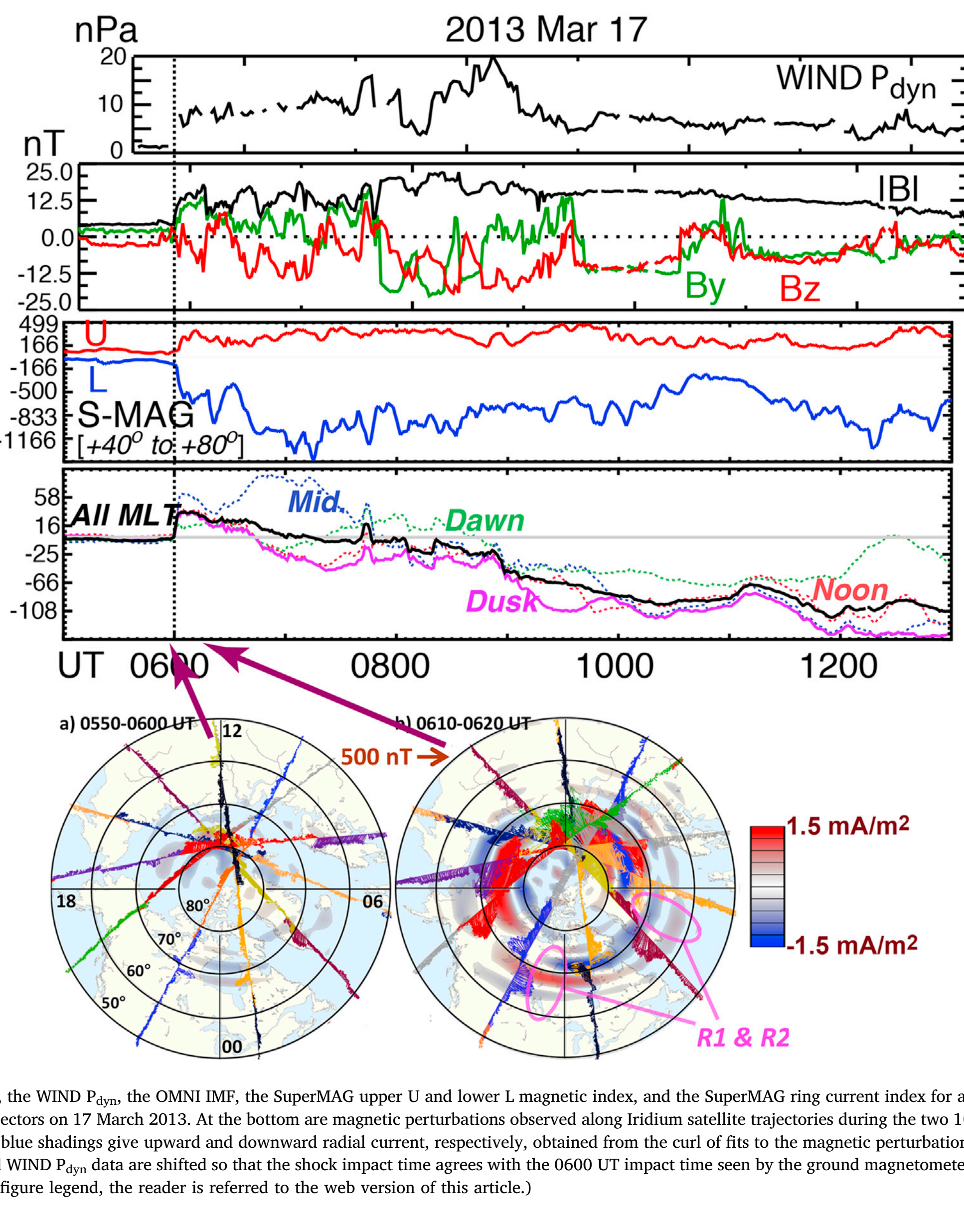

Fig. 1. From top to bottom, the WIND P_{dyn}, the OMNI IMF, the SuperMAG upper U and lower L magnetic index, and the SuperMAG ring current index for all MLT and within the dusk, noon, dawn, and midnight sectors on 17 March 2013. At the bottom are magnetic perturbations observed along Iridium satellite trajectories during the two 10 min intervals identified by the purple arrows. Red and blue shadings give upward and downward radial current, respectively, obtained from the curl of fits to the magnetic perturbations (based on Figs. 1 and 6 of Paper 1). The omni IMF and WIND P_{dyn} data are shifted so that the shock impact time agrees with the 0600 UT impact time seen by the ground magnetometers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)