Conjugate imaging of substorms

N. Østgaard, S. B. Mende, H. U. Frey, J. B. Sigwarth, A. Aasnes, and J. M. Weygand

Abstract: Simultaneous imaging in the ultraviolet wavelengths by IMAGE and Polar of substorm onset location in the conjugate hemispheres has shown that there exists a systematically displacement of substorm onset location in one hemisphere compared to the other. The relative displacement of onset locations in the conjugate hemispheres was found to be controlled primarily by the IMF clock-angle, with the dipole tilt angle as a possible second order effect. Compared with some of the existing magnetic field models, the observed asymmetries were found to be an order of magnitude larger than the model predictions. Statistical distribution of substorm onset locations in the southern and northern hemispheres for different clock angles enables us to validate the IMF clock angle control. Based on ∼3000 substorm onsets in the northern hemisphere and ∼1000 in the southern hemisphere observed by IMAGE we find a remarkable support for our previous findings.

Key words: Substorms, IMF control, aurora, imaging.

1. Introduction

In the open magnetospheric model the IMF is assumed to be an important controlling factor of solar wind-magnetosphere coupling. Theoretical considerations have suggested [17, 3] and observations have indeed shown that the IMF penetrates the outer [15] as well as the inner [22] magnetotail. The partial magnetospheric penetration [17] of the IMF has consequently been implemented in the empirical magnetic field models of Tsyganenko; T96 [18] and T02 [19, 20]. It is also well documented that the IMF orientation affects the location of the night-side aurora [2, 4, 16, 13, 7, 5]. However, to determine how auroral phenomena in the northern and southern hemispheres can be of different intensities, asymmetric or even non-conjugate, we need simultaneous conjugate measurements. In-situ conjugate measurements from space are very hard to obtain, because you do not know if you really are on conjugate field lines. Conjugate imaging from ground is difficult because you need clear sky and asymmetries that are less than the field of view of the all-sky cameras [12]. For these reasons, conjugate simultaneous global imaging from space is really what can resolve the degree of conjugacy and non-conjugacy of auroral phenomena. With an imaging cadence of 2 min and 1 min for IMAGE-FUV and Polar VIS Earth camera, respectively, these two missions have made it possible to address some of these questions more quantitatively.

In this paper we report how simultaneous imaging from the conjugate hemispheres has revealed that there exists a systematically displacement of substorm onset location in one hemisphere compared to the other [9, 10]. Furthermore, we show how this asymmetry is confirmed by a huge dataset of substorm locations from the IMAGE mission [6]. Finally, we identify some questions that naturally arise from these findings.

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N. Østgaard. Department of Physics and Technology, University of Bergen, Norway
S. B. Mende and H. U. Frey. Space Sciences Laboratory, University of California, Berkeley, California, USA
J. B. Sigwarth. Goddard Space Flight Center, Greenbelt, Maryland, USA
A. Aasnes. Los Alamos National Laboratory, Los Alamos, New Mexico, USA
J. M. Weygand. Inst. of Geophys. and Plan. Physics, U.C., Los Angeles, California, USA

2. Substorm onset location in the conjugate hemispheres

In our first study [9] we investigated thirteen events where we had conjugate simultaneous images of substorm onsets and auroral features that could be easily identified. One of these events are shown in Figure 1. To identify the IMF orientation we used 10-min-average of the IMF data from Wind and ACE time-shifted to $\mathrm{X} = -10\mathrm{R_E}$ assuming planar propagation of the solar wind. In agreement with predictions [3] we found that, for southward IMF, there exists a systematic hemispherical asymmetry of substorm onset locations. This asymmetry is strongly correlated with the IMF clock angle (the clockwise angle with respect to the northward direction see Figure 2A) and that the relative displacement (ΔMLT) can be expressed as a linear function of IMF clock angle ranging from 90° to 270° (i.e., for southward IMF). We interpreted these findings as the magnetic tensions force acting on open magnetic field lines before reconnecting in the magnetotail or simply the IMF penetration of the magnetosphere. Based on a slightly larger data set [10] we found that the dipole tilt angle may act as a secondary controlling factor (next to the IMF) of the auroral asymmetries in the conjugate hemispheres. This would be consistent with the field aligned currents (FACs) being stronger in the winter than in the summer hemispheres. Such stronger night-side winter FACs were indeed found by [8] but not in the statistical distribution of FACs based on Iridium measurements [1]. We want to emphasize that the correlation coefficient for a possible dipole tilt angle effect was relatively poor (0.56) and further studies are needed to see if this effect is real. Another result reported in that paper [10] was that the two empirical magnetic field models T96 [18] and T02 [19, 20] field models replicate qualitatively the IMF induced asymmetries, but underestimate this effect by an order of magnitude. This is an important result with implications for field-line mapping, either to find conjugate points in the two ionospheres or at different locations in the magnetosphere. In a recent paper [14] it was re-

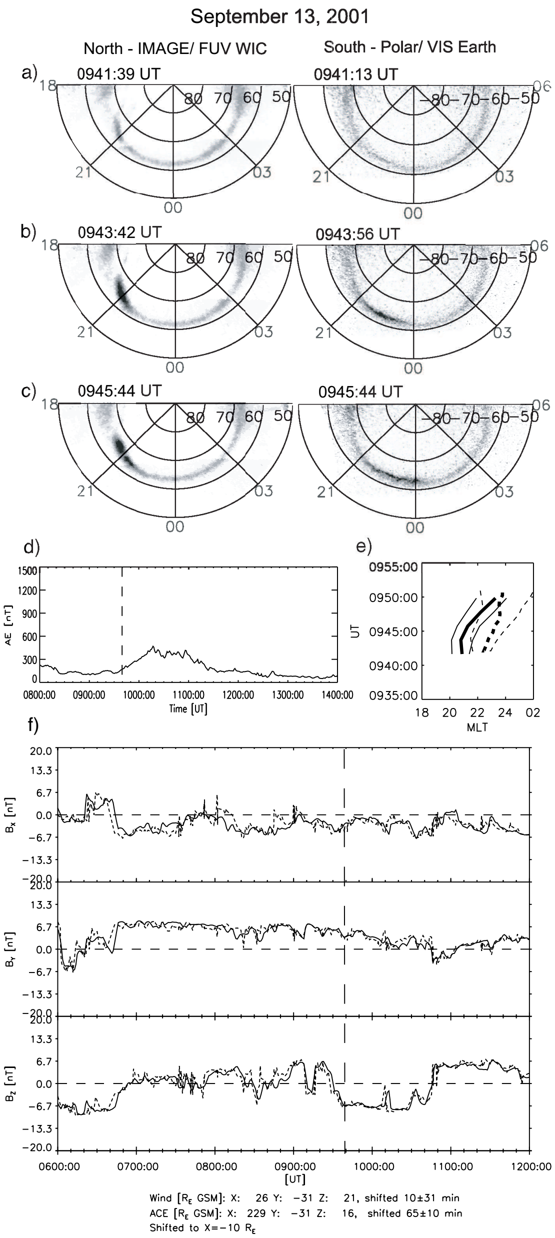

Fig. 1. September 13, 2001. (a)-(c) IMAGE WIC images from the northern hemisphere and VIS Earth images from the southern hemisphere mapped onto apex magnetic coordinates. (d) The Quick-look AE index from Kyoto, Japan. (e) The peak (thick) and the 50% intensity contour (thin) local time location for the substorm onset in the southern (dashed) and the northern (solid) hemisphere. (f) The IMF in GSM coordinates measured by Wind (solid) and ACE (dashed) time-shifted to X=-10 $\mathrm{R_E}$. This figure is from [9].

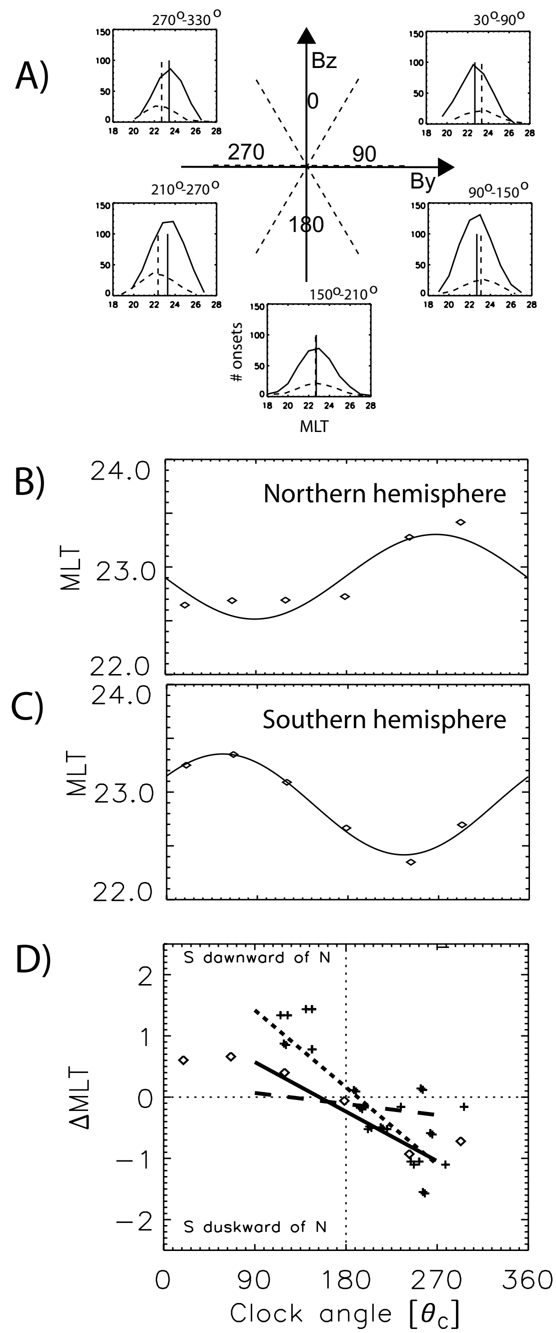

Fig. 2. (A) Statistical distributions and average of substorm onset locations in the northern (black) and southern (dashed) hemispheres for 5 different clock angle intervals of 60° using both Wind and ACE data. IMF coordinates are shown in the middle and clock angle is positive in the clockwise direction. (B) Average location of substorm onset as a function of IMF clock angle in the northern hemisphere. (C) Same for the southern hemisphere. (D) ΔMLT versus clock angle. Dotted line and crosses: Simultaneous imaging [10], black dashed line: Predicted by T02, black diamonds: points derived from (B and C), i.e., difference between average southern and northern locations, black line: regression line for black diamonds. Panel A and D were also shown by [11].

ported north-south asymmetries of the aurora that partly support and partly contradict this simple linear function (ΔMLT versus clock angle). It should be noticed, however, that the asymmetries were small, ΔMLT=0.02-0.2 and such small fluctuations might have other causes (e.g., FAC) than IMF.

To further investigate this asymmetry we have analyzed the substorm onset locations determined from IMAGE-FUV images from year 2000 to 2004 [6]. This dataset comprises 2760 and 978 substorm onset locations from the northern and southern hemisphere, respectively. For each of these substorms we have determined the 10-min-average IMF clock angle from ACE and Wind data time shifted to -10R_E using a slightly more sophisticated propagation method [21]. Cases where the clock angle varied more than 40° within the 10-min averaging interval have been excluded. In order to get sufficient statistics we binned the onset locations (MLT) in 60° intervals of IMF clock angles determined from both Wind and ACE data and calculated the average location for substorm onset in each bin for northern and southern hemisphere separately. The number of substorm locations ranges from 92 (southern hemisphere 30°-90°) to 547 (northern hemisphere 90°-150°). Figure 2A shows the distribution and average onset location in the northern (black) and southern (dashed) hemispheres for 5 of the 6 clock angle intervals. Figure 2B and C show the average substorm locations as a function of IMF clock angle (black diamonds) for northern and southern hemisphere, with a fitted cosine function overlaid (solid line). In Figure 2B you can see the relative asymmetry (southern minus northern average onset location) of the average onset locations. Even if the slope of the regression line (black line) is not as steep as derived from our simultaneous imaging data (dotted line), which one should expect from the averaging, these statistical results demonstrate that the asymmetries are still a factor 5 larger than T02 predicts (dashed line).

As mentioned a time-shift of the IMF orientation to -10R_E has been used. Considering that there is a response time for the IMF orientation to affect the inner magnetosphere, this may imply that a near-Earth neutral line has to form prior to the onset. On the other hand, if the IMF control on the inner magnetosphere is the effect of magnetic field lines reconnected at the far neutral line convected earthward a much larger time-shift is needed. To address this, we will (in the near future) check if other time-shifts, e.g., to -50R_E, -100R_E or even -100R_E plus 60 min, will give a similar systematic IMF control.

3. Conclusions

In this paper we have reviewed and discussed our main results from analyzing global imaging data by IMAGE and Polar.

(1) There exists a systematical asymmetry of substorm onset locations in the conjugate hemispheres, which is found to be controlled primarily by the IMF clock angle.

(2) Compared with some of the existing magnetic field models, the observed asymmetries are an order of magnitude larger than the model predictions.

(3) These results have been compared with the statistical distribution of substorm onsets observed by IMAGE for different clock angles. Based on ∼3000 substorm onsets in the northern hemisphere and ∼1000 in the southern hemisphere we find a remarkable support for our previous findings. The asymmetries are at least 5 times larger than model predictions.

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