Impact angle control of interplanetary shock geoeffectiveness

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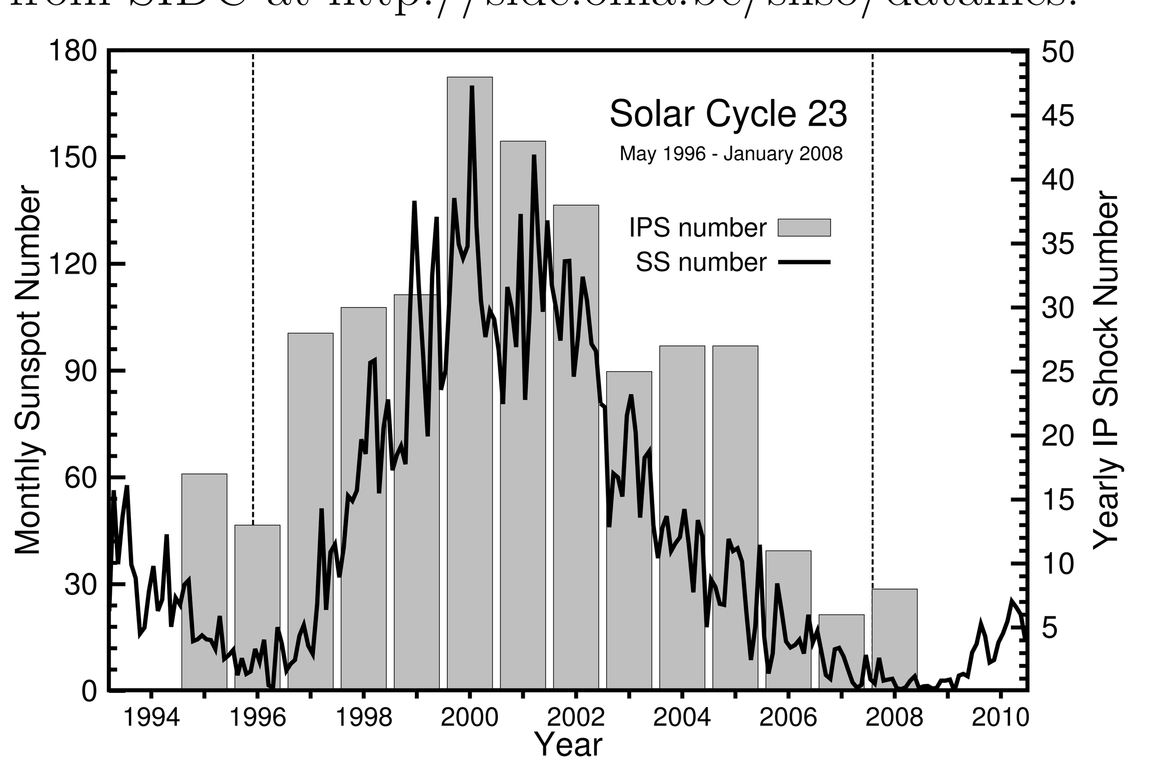
Motivation

The motivation for this research is to understand how the interplanetary (IP) shock geometry affects the shock geoeffectiveness. In a paper recently published by Oliveira and Raeder [2014], it is shown that the shock geoeffectiveness depends on the IP shock inclination in relation to the Sun-Earth line, where shocks with small impact angles (θ_{x_n}) are more geoeffective. Our main goal is to carry out a statistical study of satellite and geomagnetic activity data and their correlations via shock normal (SN) orientations and shock strength.

Data

The data set used in this study is composite of fast forward IP shocks found at different sources, such as http://www.cfa.harvard.edu/shocks/ (Wind and ACE), and UNH's http://www-ssg.sr.unh.edu/mag/ace/ACElists/obslist.html#shocks (ACE). Also we used a searching computer program to look for possible shock candidates that were not present in these lists. The geomagnetic index data (AL, Ap, and SYM-H) were downloaded from http://wdc.kugi.kyoto-u.ac.jp/aeasy/index.html. The monthly sunspot number data were obtained from SIDC at http://sidc.oma.be/silso/datafiles.



Shock normal determination

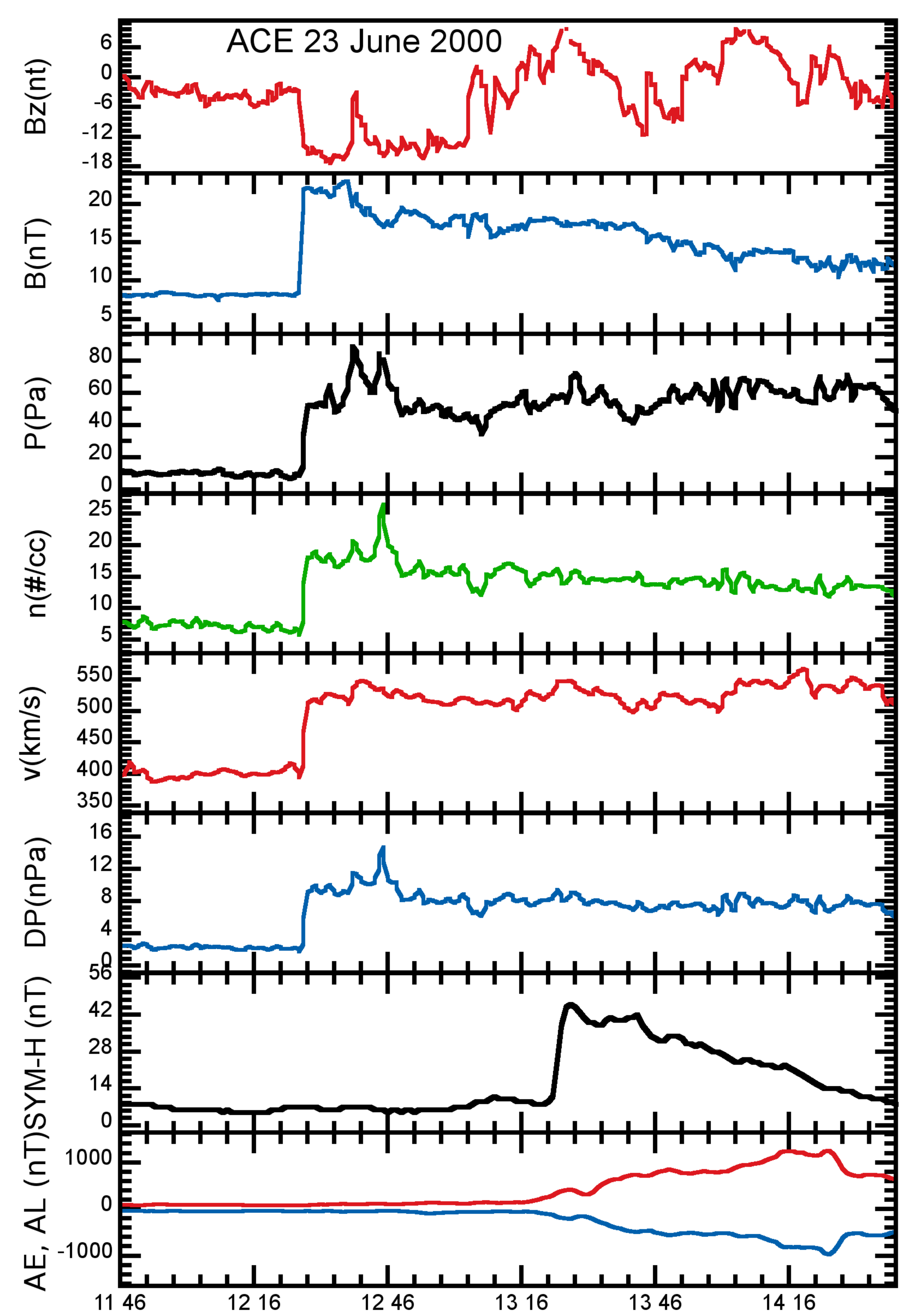
- Shock normals were obtained using the magnetic coplanarity, velocity coplanarity, and mixed data methods.
- The upstream and downstream conditions are chosen ∓1-2 min before/after the shock is seen by the spacecraft. They are then calculated as the 10 minute average of each plasma parameter.
- The shock normal chosen as the "best" solution for each event was the average of at least three close results by a factor of $\pm 15^o$ in θ_{x_n}.

Geomagnetic activity analysis

- We chose three geomagnetic indices: AL (jump), Ap, and SYM-H (jump) for high, medium, and low geomagnetic latitudes.
- The time resolution is as follows: ∼30-60 min for AL, ∼4-30 min for SYM-H, and ∼3-6 hours for Ap after shock-magnetopause interaction.

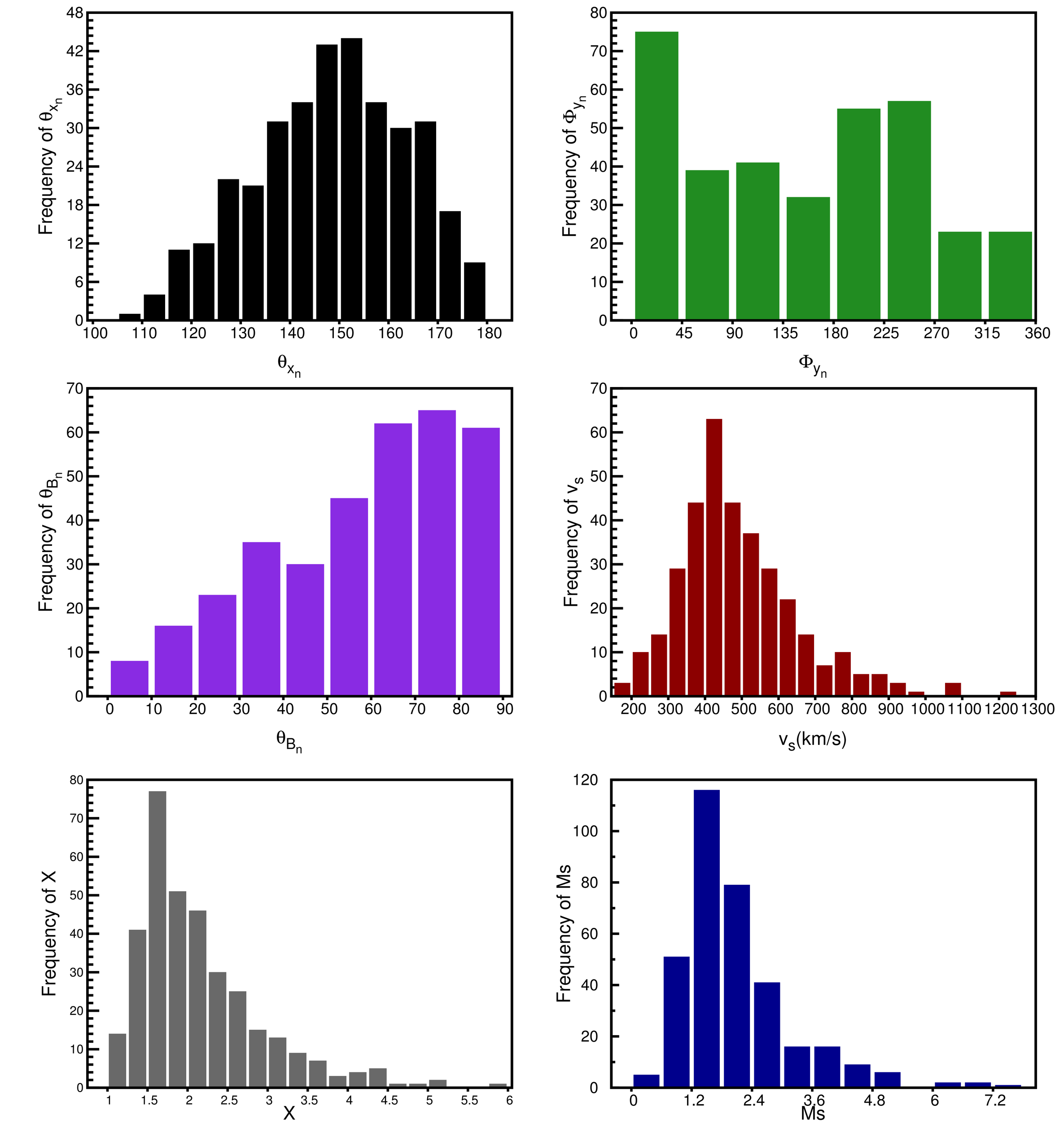
Example of an event

The figure below is an example of an event on 2000 Jun 23 at 1226 UT as seen by ACE at (240, 36.6,-0.7) R_E upstream of the Earth. The shock normal of this event is (-0.758,0.163,-0.625), with θ_{x_n} ∼140^o, shock speed of 553.2 km/s, and fast magnetosonic Mach number 2.60 The compression ratio (the ratio of downstream to upstream plasma density) is 2.62.

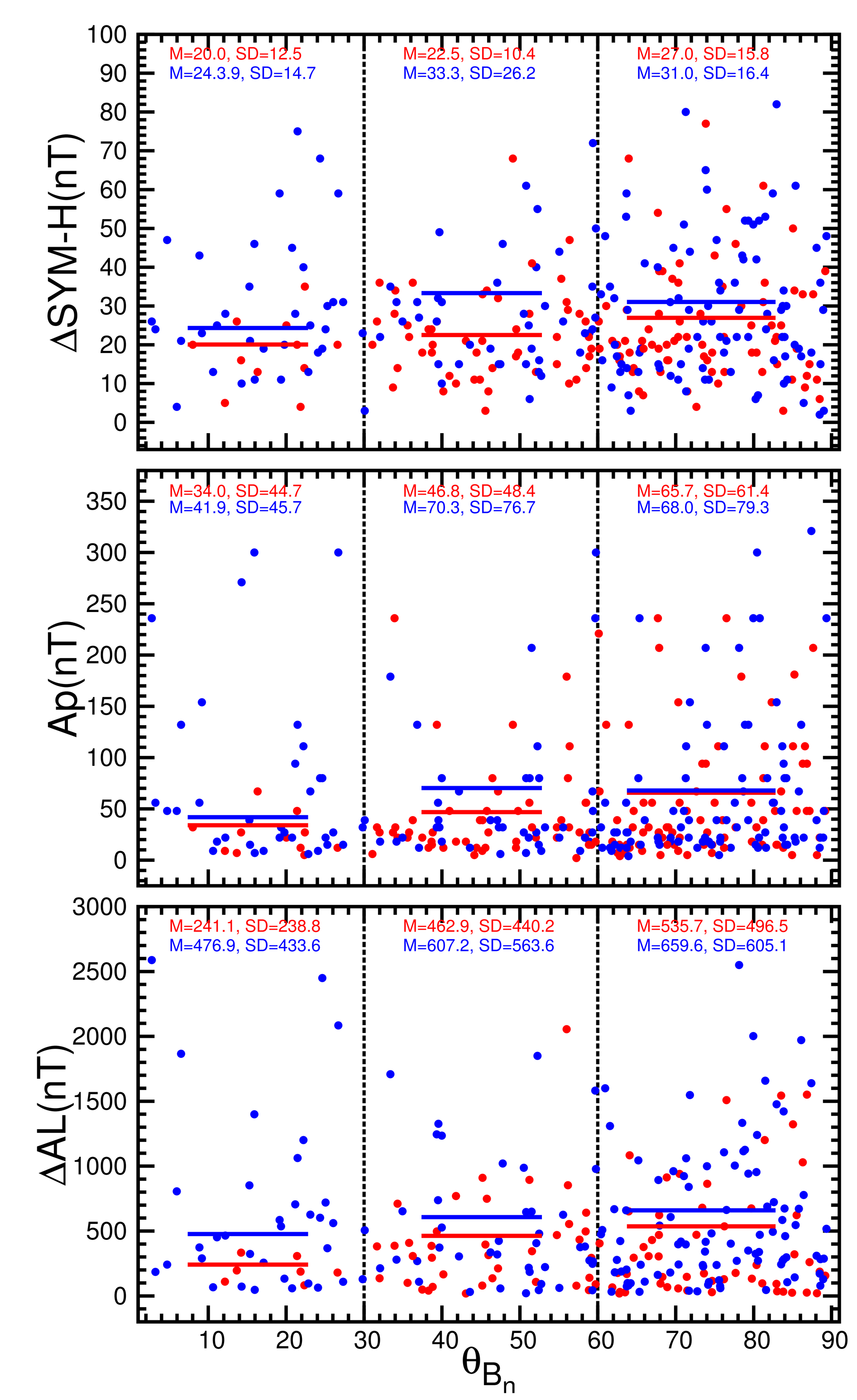


Statistical results

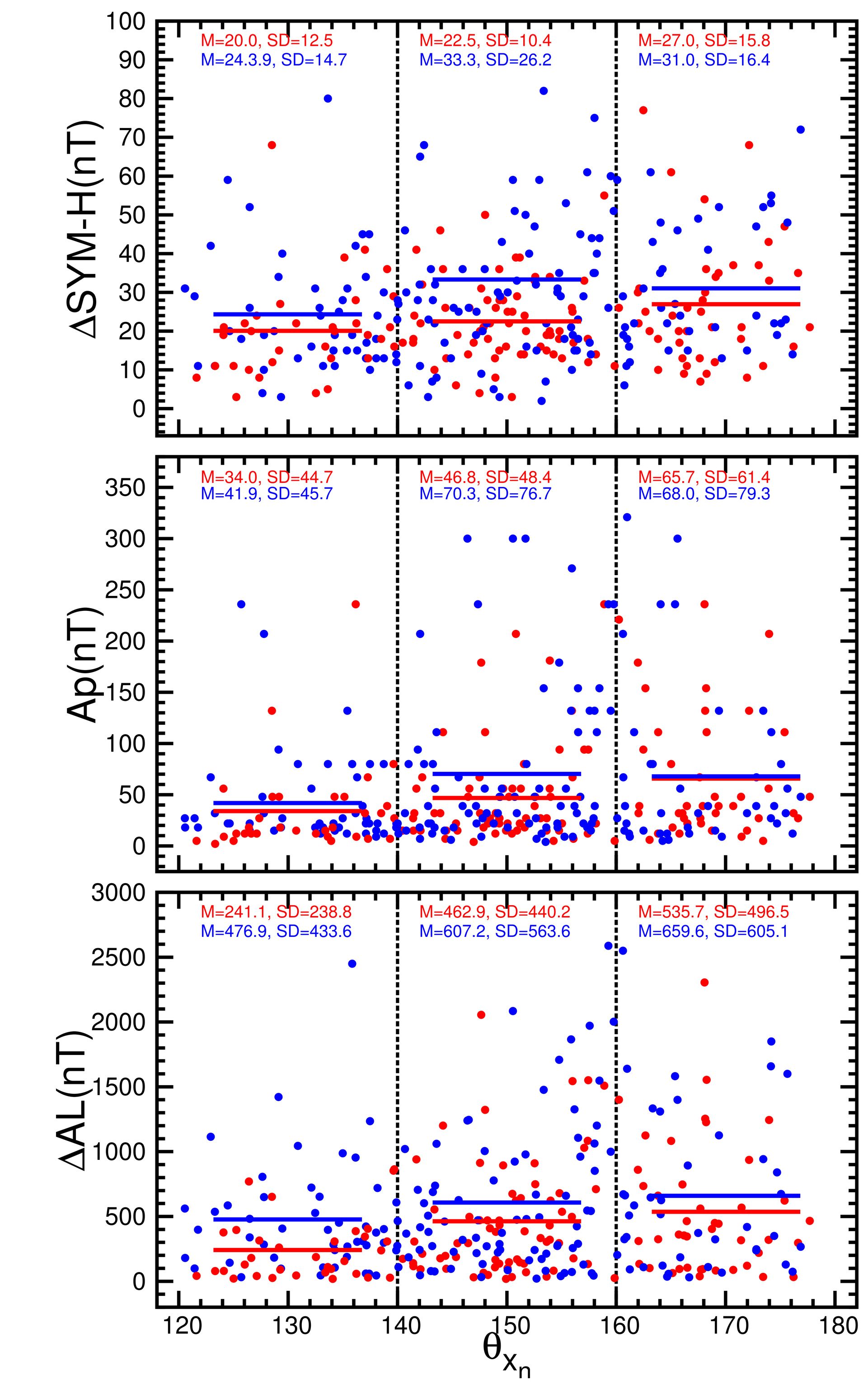
Our shock list is composite of 328 identified IP shocks from 1995-2008, covering the whole solar cycle 23. Solar wind and IP shock data are shown in the first plot in the next column.



Below, the three investigated geomagnetic indices plotted against θ_{B_n} for the whole solar cycle 23. Data in red correspond to the ascending phase (1996-2000, 151 IP shocks), and data in blue correspond to the declining phase (2001-2008, 177 IP shocks) of the solar cycle 23. Parallel straight lines are averages. The declining phase is more geoeffective than the ascending phase. Quasi-perpendicular shocks are more geoeffective on average.



ΔSYM-H, Ap, and ΔAL indices are plotted versus θ_{x_n} below. Impact angles closer to 180^o represent almost frontal shocks. They were binned in three different groups: highly oblique ($120^o \leq \theta_{x_n} \leq 140^o$), oblique ($140^o \leq \theta_{x_n} \leq 160^o$), and almost head-on ($160^o \leq \theta_{x_n} \leq 180^o$). On average, almost head-on shocks are more geoeffective.



Conclusion

- The number of IP shocks correlates well with the monthly sunspot number.
- The majority of the events (73%) are almost perpendicular shocks, with $\theta_{B_n} \geq 45^o$. Most shocks (78%) have their shock normals close to the Sun-Earth line, or $\theta_{x_n} \geq 135^o$.
- As expected, on average, IP shocks during the declining phase are more geoeffective than IP shocks during the ascending phase of solar cycle 23.
- Almost perpendicular shocks are more geoeffective than oblique and highly oblique shocks. Almost head-on shocks, on average, are more geoeffective than highly inclined IP shocks. This result was predicted by Oliveira and Raeder [2014].

References

D. M. Oliveira and J. Raeder. Impact angle control of interplanetary shock geoeffectiveness. *J. Geophys. Res.*, 119(10):8188–8201, 2014. doi:10.1002/2014JA020275.