Role of symmetry in the geo-effectiveness of interplanetary shocks

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Introduction

In this study we investigate the interaction of interplanetary (IP) shocks with Earth's magnetosphere using OpenGGCM global simulations. In particular we are interested in the effects of IP shocks on the tail and the ionosphere. We find that the IP shock angle, that is, the angle between the shock normal and the sun-Earth line, plays a major role determining the geo-effectiveness of the IP shock. For most IP shocks this angle is large. In such cases, the shock hits one side of the magnetosphere first, pushing the tail either sideways or in the north or south direction. Waves generated by the shock/magnetosphere interaction travel through the magnetosphere without much effect. The response of the magnetosphere is thus rather mild, because the shock does not effectively compress the magnetosphere. In cases where the shock angle is small, the magnetosphere response is much stronger. Because of the symmetry, shock-induced waves converge in the tail, producing a strong compression. The compression, in turn, triggers reconnection, and possibly a substorm, with large effects on the ionosphere. We thus conclude that the geo-effectiveness of interplanetary shocks is not just a function of their strength, i.e., Mach number, but also, and possibly much more so, a function of their impact angle.

The Rankine-Hugoniot equations

$$[\rho v_n] = 0$$
$$[B_n] = 0$$
$$\left[\rho v^2 + P + \frac{B_t^2}{2\mu_0}\right] = 0$$
$$\left[\rho v_n v_t - \frac{B_n B_t}{4\pi}\right] = 0$$
$$\left[\left(\frac{1}{2}\rho v^2 + \frac{P}{\gamma - 1} + P + \frac{B^2}{\mu_0}\right) v_n - (\mathbf{v}\cdot\mathbf{B})\frac{B_n}{\mu_0}\right] = 0$$
$$[\mathbf{v}_n \times \mathbf{B}_t + \mathbf{v}_t \times \mathbf{B}_n] = 0$$

Oblique Shock

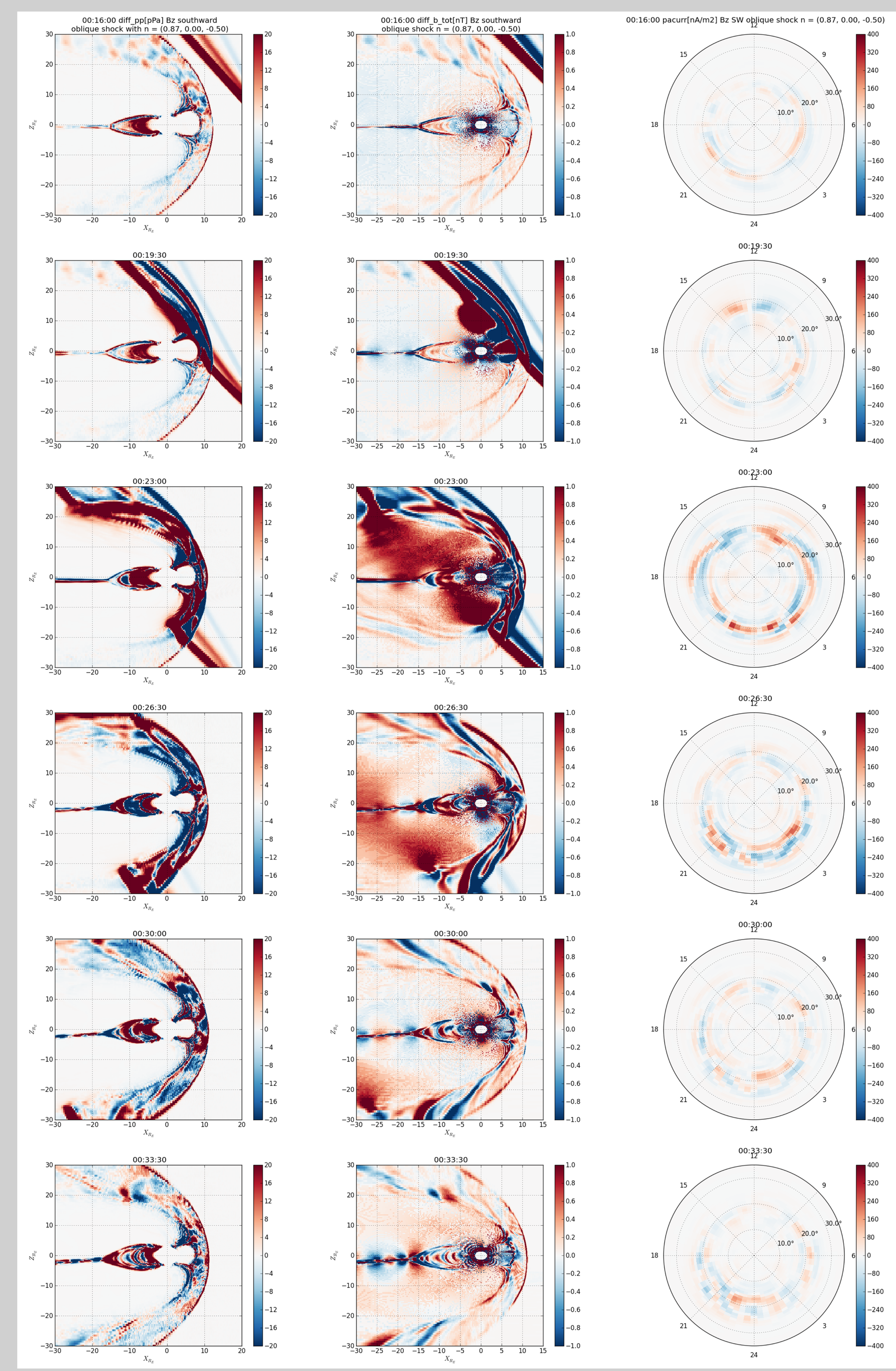

Figure 1: 6 consecutive frames representing the result of simulations with impact angle of 30^o. From left to right, plots indicate difference in plasma pressure, total magnetic field and parallel current in the ionosphere. Data is shown in Table 1.

Table 1: RH solutions for oblique, B_z southward shocks.

plasma parameters	0^o	30^o	45^o
P_1, pPa	20.00	20.00	20.00
n_1, part/cm^3	5.00	5.00	5.00
M_A	3.63	2.65	2.56
B_{x1}, nT	5.00	1.83	0.00
B_{y1}, nT	0.00	0.00	0.00
B_{z1}, nT	-5.00	-6.83	-7.07
v_{x1}, km/s	400.00	400.00	400.00
v_{y1}, km/s	0.00	0.00	0.00
v_{z1}, km/s	0.00	0.00	0.00
P_2, pPa	108.15	67.41	64.23
n_2, part/cm^3	7.50	7.50	7.50
B_{x2}, nT	5.00	0.50	-1.89
B_{y2}, nT	0.00	0.00	0.00
B_{z2}, nT	-7.58	-9.13	-8.96
v_{x2}, km/s	483.38	455.00	446.20
v_{y2}, km/s	0.00	0.00	0.00
v_{z2}, km/s	-4.39	-25.16	-37.13

Perpendicular Shock

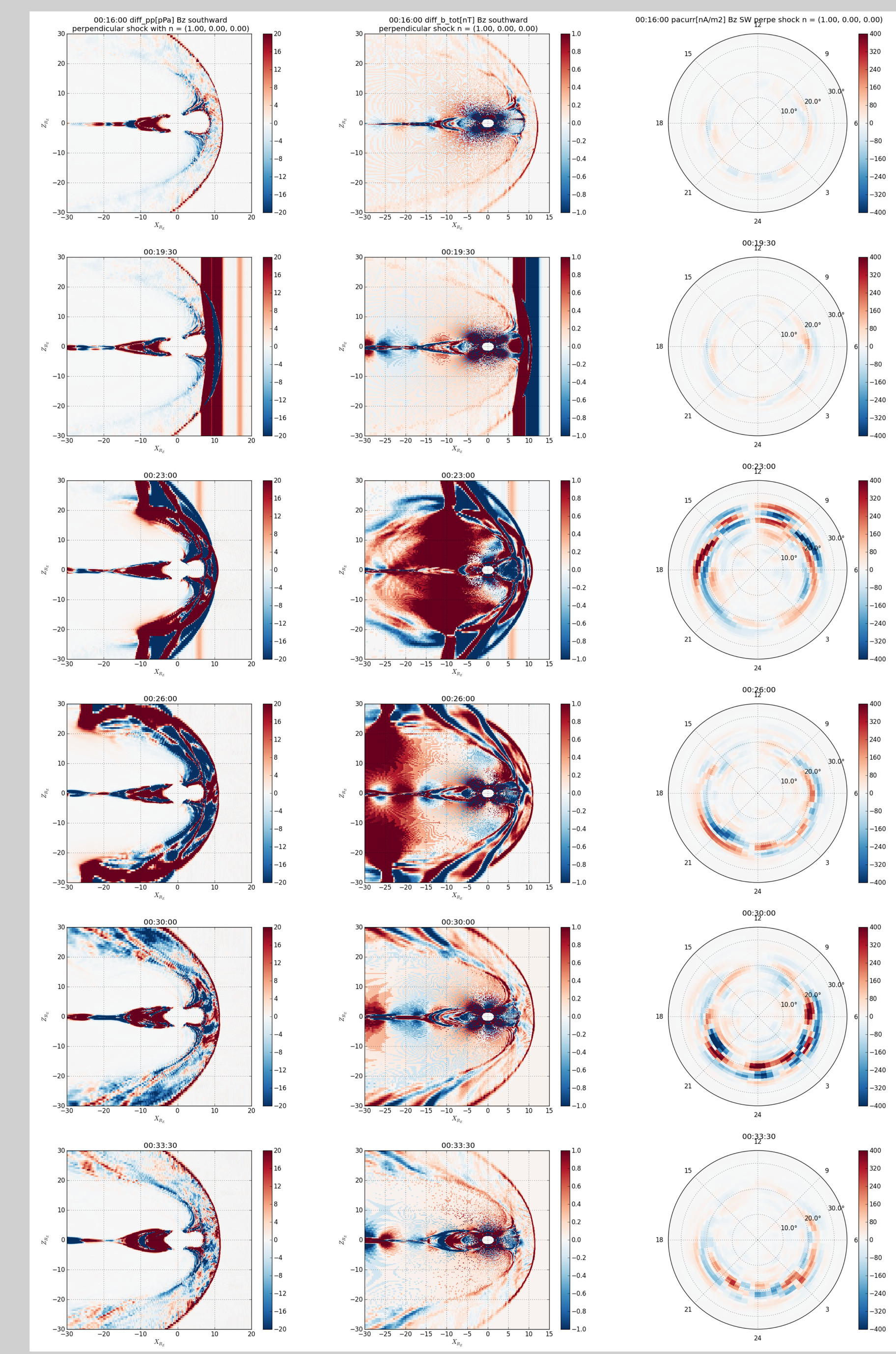

Figure 2: Same plot sequence for IP angle of 0^o degrees. In this case, the shock normal is parallel to the Earth-Sun line. Effects on the tail and nightside ionosphere are more intense. Data is shown in Table 2.

Table 2: RH solutions for perpendicular, B_z southward shocks.

plasma parameters	0^o	30^o	45^o
P_1, pPa	20.00	20.00	20.00
n_1, part/cm^3	5.00	5.00	5.00
M_A	3.63	2.73	1.22
B_{x1}, nT	0.00	-3.54	-5.00
B_{y1}, nT	0.00	0.00	0.00
B_{z1}, nT	-7.07	-6.12	-5.05
v_{x1}, km/s	400.00	400.00	400.00
v_{y1}, km/s	0.00	0.00	0.00
v_{z1}, km/s	0.00	0.00	0.00
P_2, pPa	141.15	77.81	31.75
n_2, part/cm^3	7.50	7.50	7.50
B_{x2}, nT	0.00	-5.30	-7.50
B_{y2}, nT	0.00	0.00	0.00
B_{z2}, nT	-10.61	-9.18	-7.50
v_{x2}, km/s	483.33	454.31	419.87
v_{y2}, km/s	0.00	0.00	0.00
v_{z2}, km/s	0.00	-31.35	-19.87

SW Initial conditions

We solve the Rankine-Hugoniot equations for plasma parameters of a quiet solar wind as initial condition in two different shocks. Such parameters are represented in Tables 1 and 2. Using OpenGGCM, we plot the plasma pressure, total magnetic field, and parallel current in the ionosphere taking the difference between two consecutive data files from our simulations. With a compression ratio of 1.5, the shock speed is chosen to be 650 kms^{-1} and the upstream solar wind speed is set in a frame of reference where $\mathbf{v_1} = (400, 0, 0)$ kms^{-1} in both cases. The modeled normal shock is set to lie in the xz plane and, as a result, all of its y components for $\mathbf{B}$ and $\mathbf{v}$ are null. We present two different kinds of shocks: an oblique case, where $\theta_b = 45^o$ is the angle between the magnetic vector and the shock normal. The other class is the perpendicular shock, since $\theta_b = 90^o$. In the oblique case, the frame of reference chosen is the Teller-Hoffman frame of reference, where $\mathbf{v} \parallel \mathbf{B}$.

Conclusion

We conclude that the Earth's magnetosphere responds to IP shocks in different ways depending on the impact angle. The response is stronger for the z component of the IMF directed southward.

- The tail is more compressed for a perpendicular shock with small impact angle in comparison to an oblique shock with larger angles.
- Such a compression can trigger reconnection in the tail and more intense effects on the nightside of the ionosphere.
- The effect of inclined shocks is to twist the tail.

Contact Information

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