Global MHD Modeling of the Impact of a Solar Wind Pressure Change at the CCMC

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Abstract

A sudden increase in the solar wind dynamic pressure compresses the magnetosphere and launches compressional waves into the magnetosphere. Sudden changes in the solar wind dynamic pressure also trigger longer period ground pulsations. Using BATS-R-US, a global 3D adaptive MHD model developed at the University of Michigan, we will simulate a sudden increase in the solar wind dynamic pressure by using a density pulse. We will study the response of the magnetosphere to the density pulse. We will also study the generation of field-aligned currents and the response of the ionosphere. We will also discuss the use of global MHD as a space weather prediction tool.

Current Theories About Solar Wind Pressure Pulses

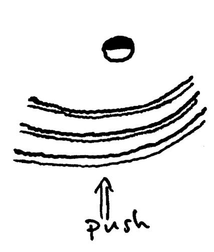
- Propagation of a wave along the magnetopause (Sibeck, Glassmeier, Kivelson and Southwood). Field-aligned current generation is near the magnetopause.
- Propagation of a MHD wave into the magnetosphere setting up a field line resonance (Lysak, Araki). Field-aligned current generation is well-inside the magnetosphere.
- Field-aligned current being generated by changes in pressure and flux tube volume inside the magnetosphere (Hesse). Field-aligned current generation is well-inside the magnetosphere.

Field-Aligned Current Generation due to Changes in Flux Tube Volume and Pressure

Starting with $\frac{j_{\parallel}}{B} = -\frac{1}{V^g}\frac{\mathbf{B}_{eq}}{B^2}\cdot[\nabla(pV^g)\times\nabla V]$ [Vasyliunas]

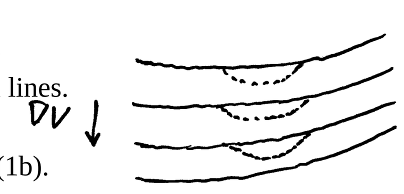
where $V = \int\frac{ds}{B}$, field-aligned current can be generated by the following argument:

Before impact of the pressure pulse, the contours of V and pV^γ are shown in (1a)



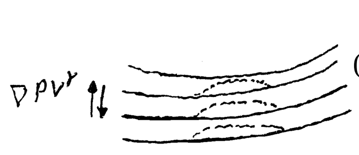
(1a)

Compression of the magnetopause leads to an increase in B and shortening of the field lines. At a fixed location, V will decrease. The new contours are shown as dotted lines in (1b).



(1b)

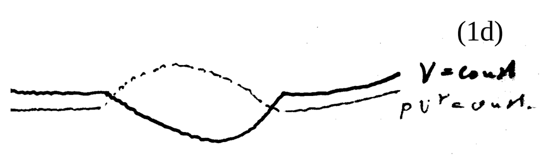
pV^γ is conserved along the flow lines of the compressive velocity so the new contours are shown as dotted lines in (1c).



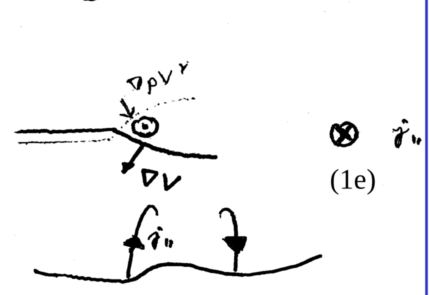
(1c)

(1d)

Locally, the contours of pV^γ and V will look like (1d) and are at an angle.



Since the gradients are orthogonal to contours, a finite $j_{||}$ results. The sign of $j_{||}$ is shown in (1e) for an outward gradient of pV^γ. The signs are the opposite for an inward gradient of pV^γ.



(1e)

Observations

- Observations indicate field-aligned current is often seen on closed field lines well-inside the open-closed field line boundary with frequency spectra that do not match field line resonances (Rodgers, Sibeck, Bern TCV workshop).

Goals of the Study

- A scientific test of the BATS-R-US code developed by the University of Michigan.
- Study field-aligned current generation due to a pressure pulse.
- Study the response of the ionosphere to the pressure pulse.
- Compare to the model predictions.

Simulation Information

- The simulation uses adaptive mesh refinement with the smallest resolution being .25 R_E. The typical number of cells is around 800,000.
- The box goes from 32 R_E to –96 R_E in the *x* direction and from 32 R_E to –32 R_E in the *y* and *z* direction.
- The inner boundary is at 3 R_E.

Solar Wind Plasma Data

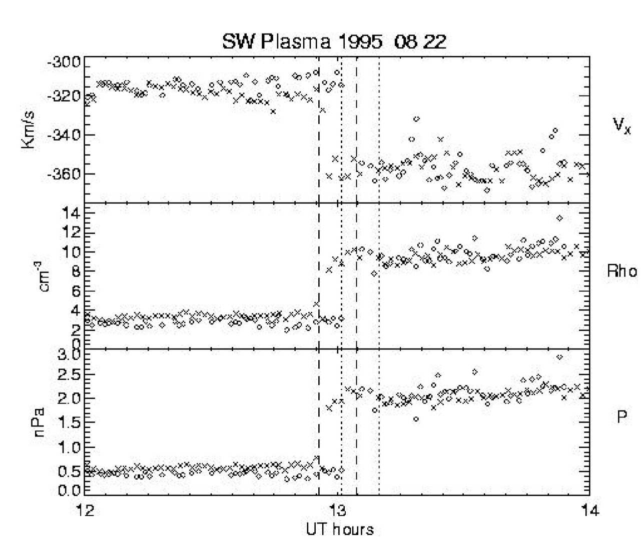


Figure 2. This is solar wind plasma data for 8/22/1995 supplied by Therese Moretto that was used as a guide to our solar wind data. This is a typical event. In our case, the velocity was kept constant with an average of 340 km/s.

Solar Wind Boundary Conditions

- Increase the density from 2.5 cm^{-3} to 10 cm^{-3} during the time period of *t* = 15 min to 25 min.
- The solar wind v_x is kept constant at 340 km/s while v_y and v_z are randomly generated with a maximum of 10 km/s.
- The IMF is northward. The magnitude is 1 nT.

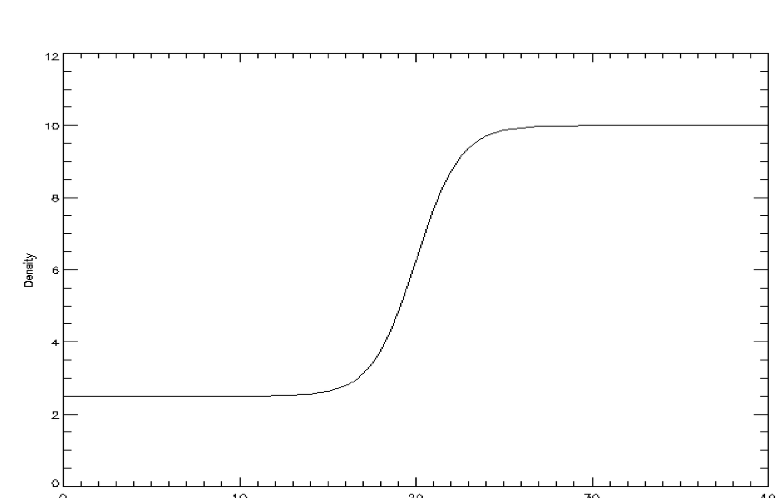


Figure 3. Solar wind density as a function of time.

Ionospheric Model

- Constant Pedersen conductivity with Σ_P = 5 mhos.
- $j_{||}$ mapped from 4 R_E to the ionosphere.
- In the ionosphere, the potential is calculated using $j_{||}$.
- The potential is mapped back to the magnetosphere to get the velocity and electric field.

Density in the Noon-Midnight Plane

(a)

(b)

(c)

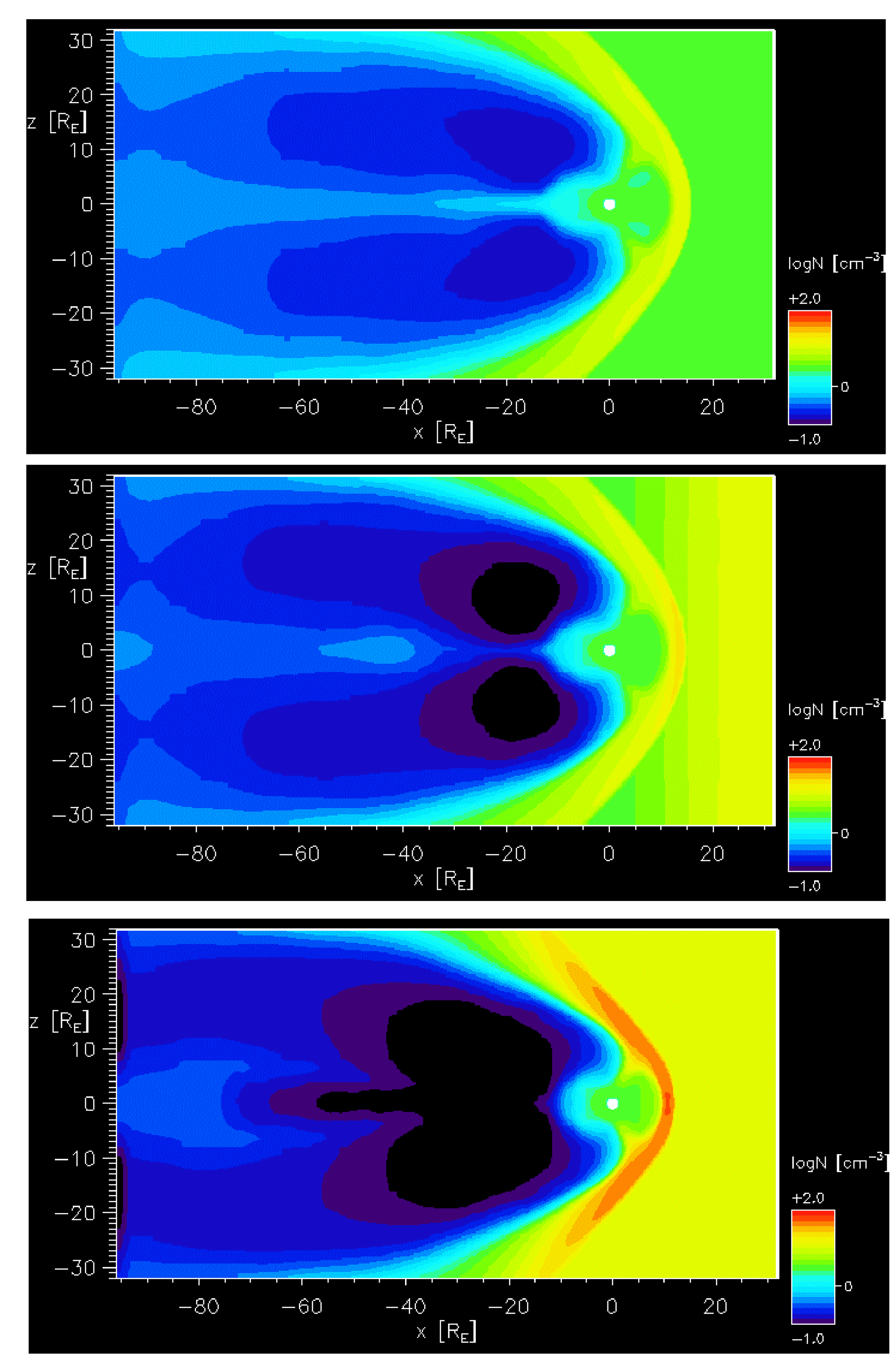


Figure 4. Plots of the log(density) in the *y* = 0 plane at (a) *t* = 15 min, (b) *t* = 25 min and (c) *t* = 35 min. The density increase is started at 15 minutes and has reached the bow shock by 25 minutes.

Density in the Equatorial Plane

(a)

(b)

(c)

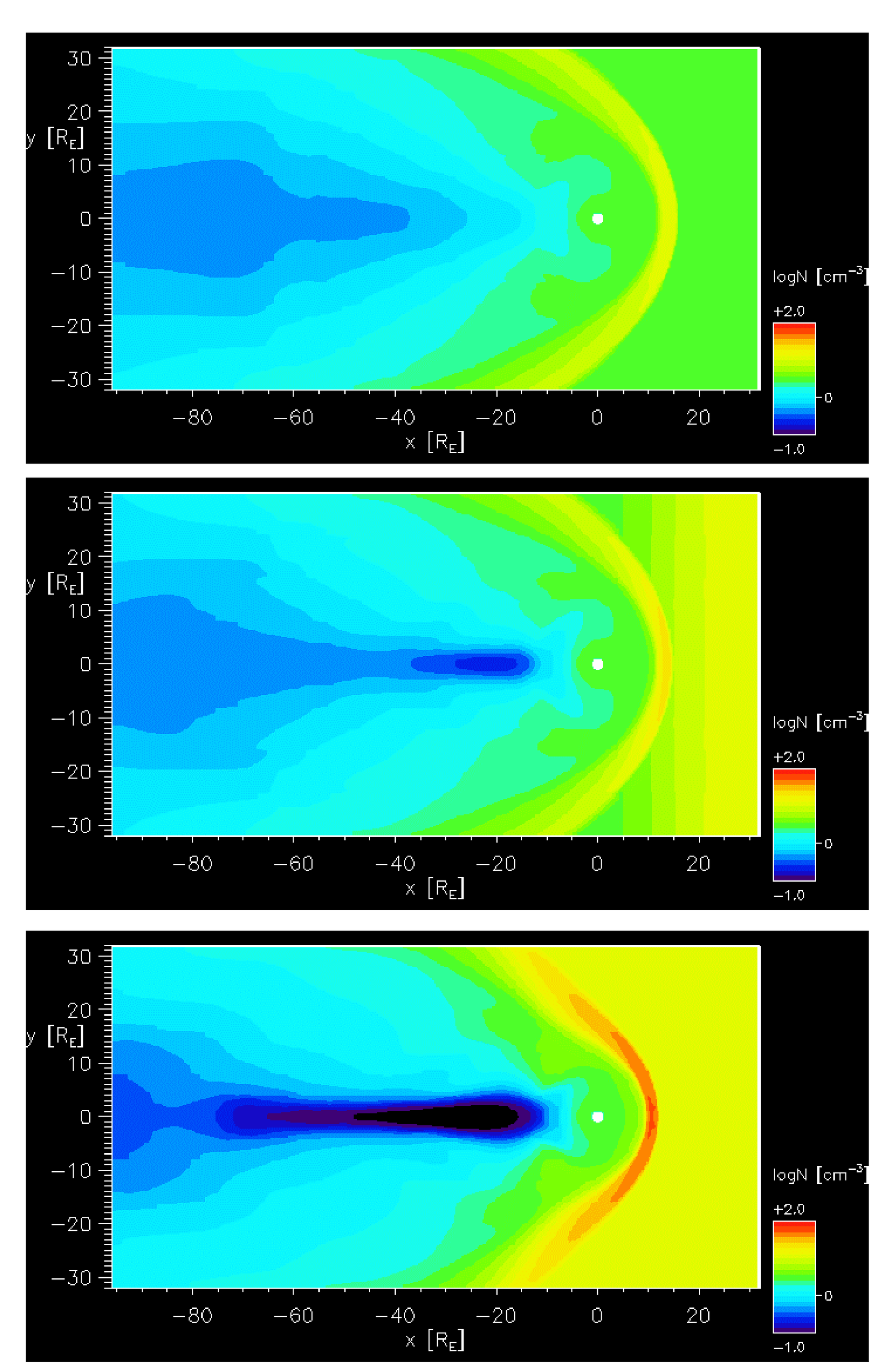


Figure 5. Plots of the log(density) in the *z* = 0 plane at (a) *t* = 15 min, (b) *t* = 25 min and (c) *t* = 35 min. The density increase is started at 15 minutes and has reached the bow shock by 25 minutes.

Current Density in the Ionosphere

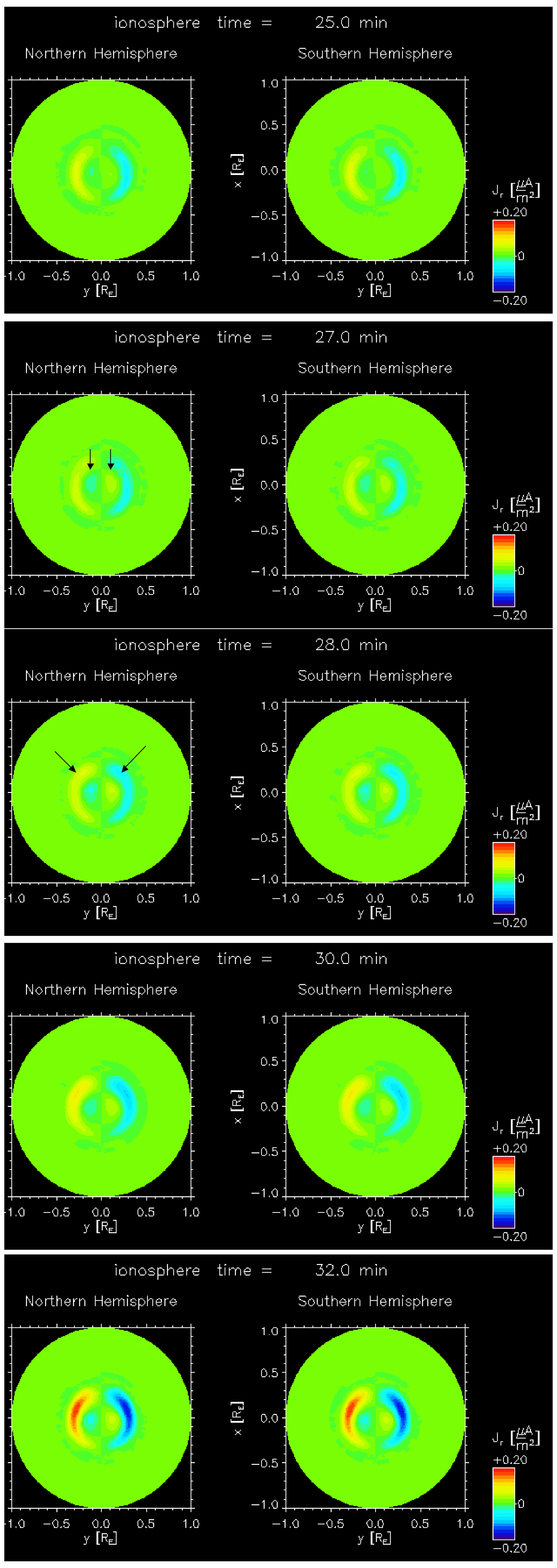


Figure 6. The field-aligned current density in the ionosphere. At t = 25 minutes (a), the front-edge of the pressure pulse hits the magnetosphere. At t = 27 minutes (b), there is an increase in the magnitude of the current density near the poles. At t = 28 minutes (c), the sunward edge of the equatorward current pattern starts to increase. This pattern has the opposite direction of the poleward current density. At later times, the increase in the magnitude of the current density moves tailward. The results from the simulation approximately agree with the results from *Moretto et al.* [2000] for 8/22/1995.

Current Density at z = 1 R_e

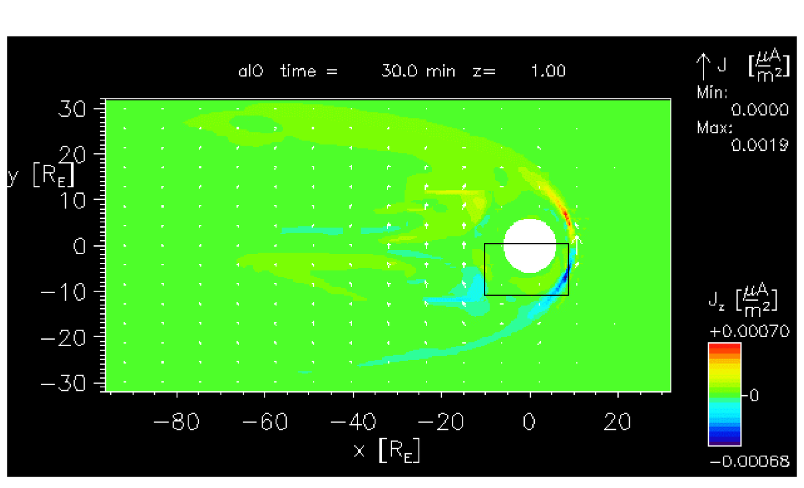


Figure 7. The vectors are the components of current density in the x-y plane at z =1 R_E. The color contour is j_z. At z =1 R_E, j_z approximates the field-aligned current density. The largest magnitude of j_z occurs near the magnetopause. The next figures will show current density in the region from x = -12 to 12 R_E and from y = -12 to 0 R_E. This region has a + j_z and is shown by the box in the figure.

Current Density at z =1 R_E

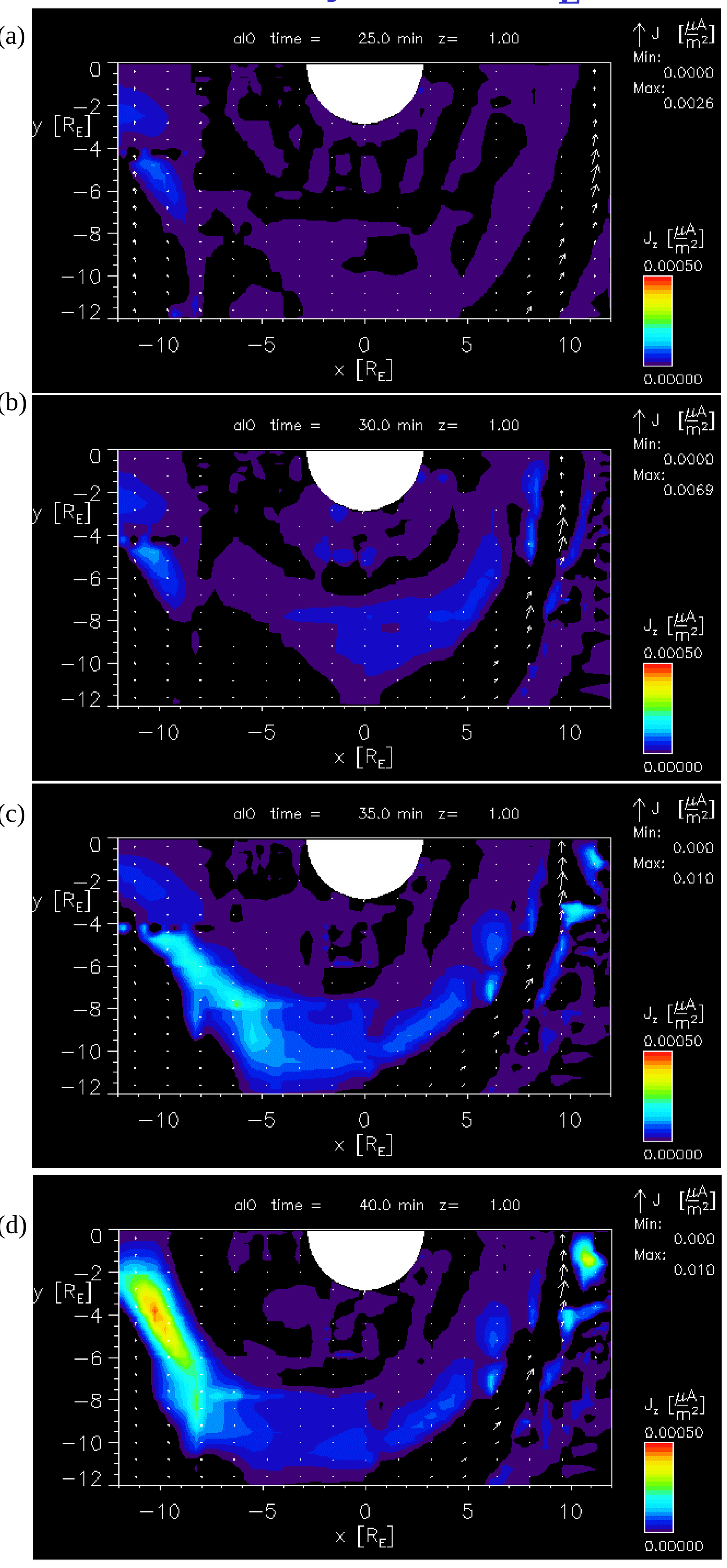


Figure 8. The vectors are the components of current density in the x-y plane at z =1 R_E. The color contour is j_z. At t = 25 minutes (a), the front-edge of the pressure pulse hits the magnetosphere. At t = 30 minutes (b), j_z has increased on the dayside of the magnetopause. At t = 35 minutes (c), the increase in j_z has moved tailward and continues to increase at t = 40 minutes (d). This increase in current density is well-inside the magnetopause.

Current Density at x = 0

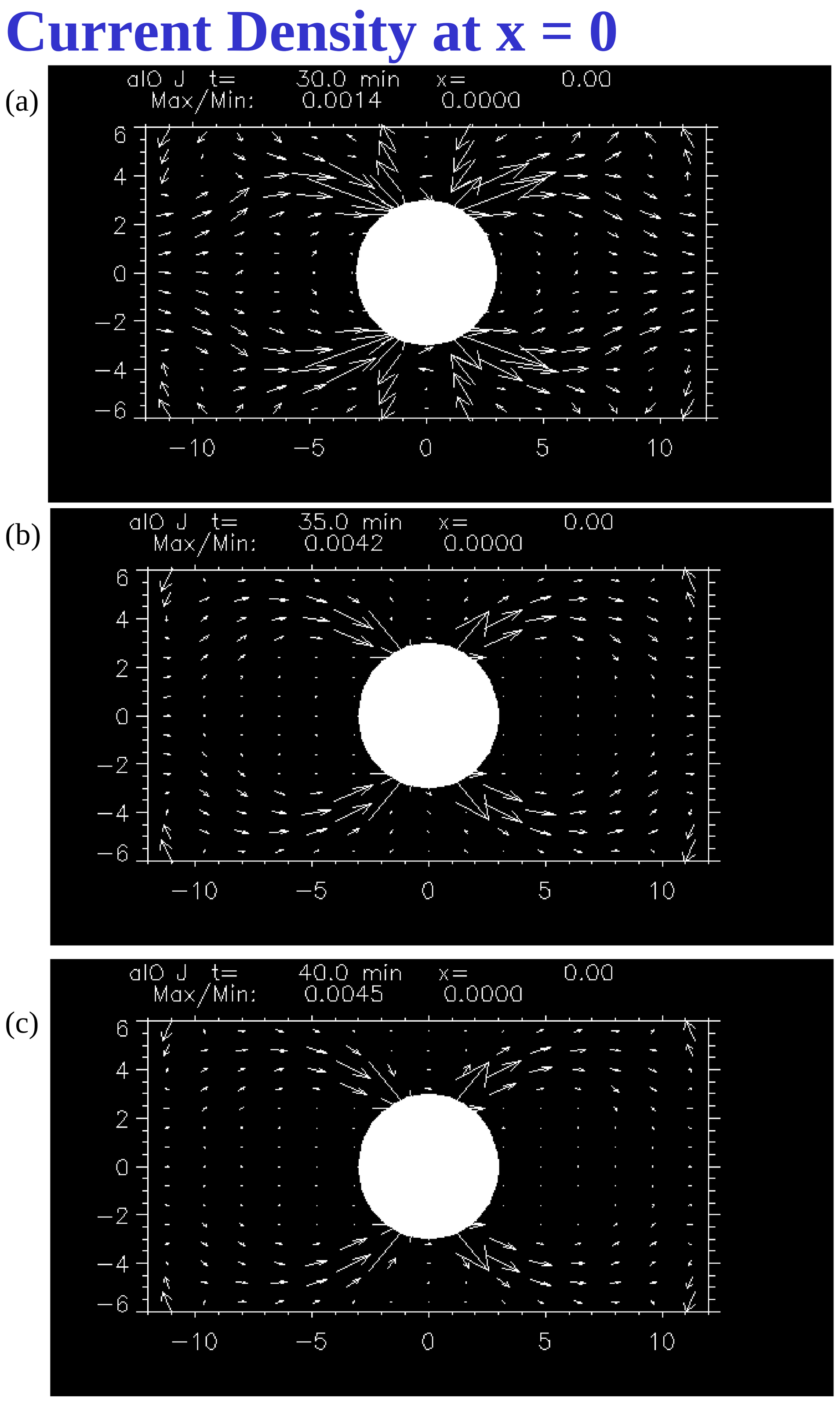


Figure 9. The vectors are the components of current density in the y-z plane at x =0. The maximum current density increased by a factor of 3 from t = 30 minutes to t = 35 minutes.

Flux Tube Volume (V) and pV^g at z=0

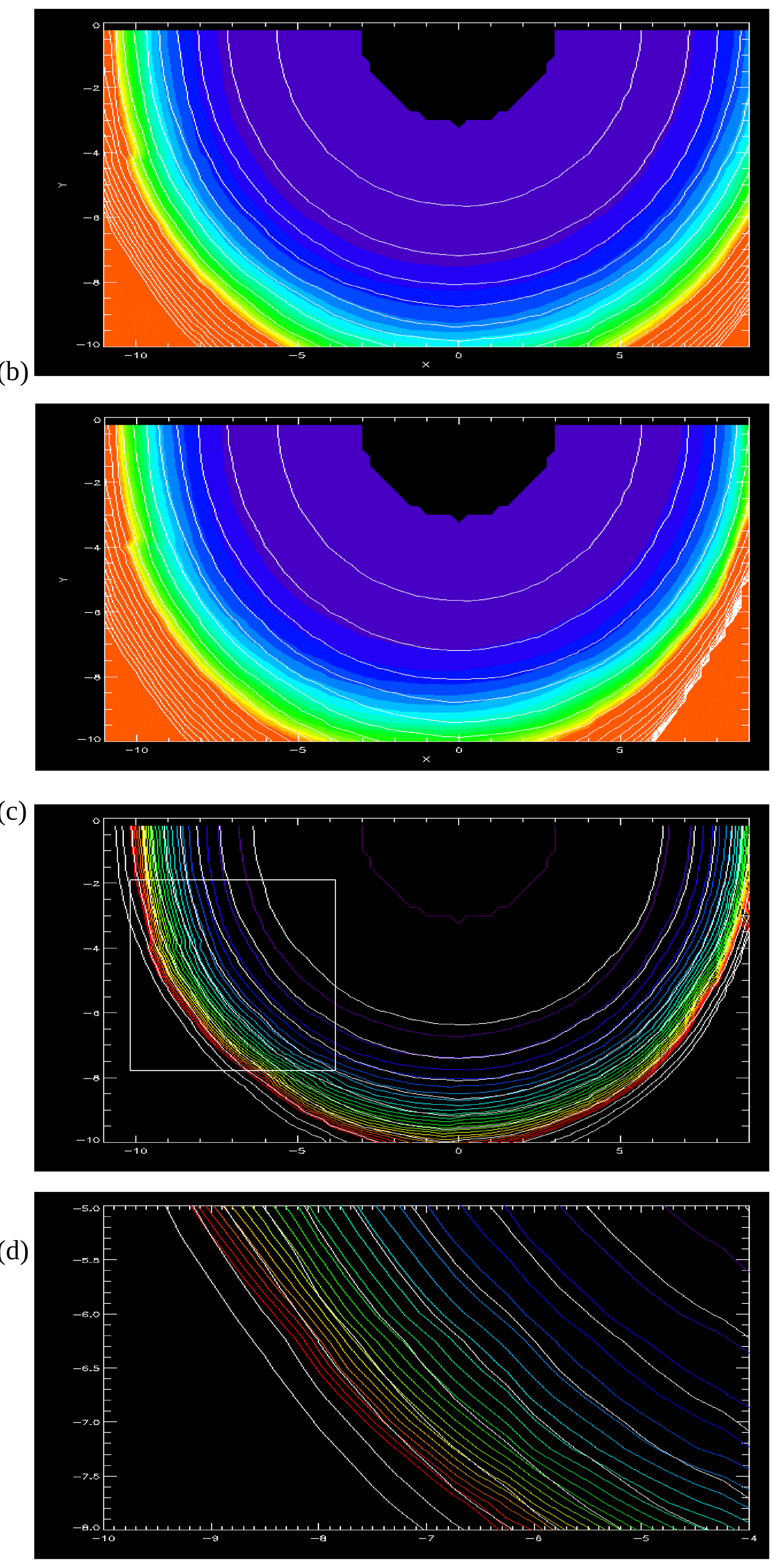


Figure 10. The white contour lines are the contours of the flux tube volume V. The color contours are pV^g. The plane is z = 0 R_E. At t = 25 minutes (a), the front-edge of the pressure pulse hits the magnetosphere. At t = 30 minutes (b), the two contours intersect in the region near x = 0, where j_z has increased. At t = 35 minutes (c), the contours of V and pV^g intersect in the region -10 R_E < x < -4 R_E and -8 R_E < x < -5 R_E where j_z has increased. The region -10 R_E < x < -4 R_E and -8 R_E < x < -5 R_E is shown in (d).

Summary

- The magnetosphere is compressed starting around t = 25 min.
- There is an increase in the current density and electric potential in the ionosphere.
- There is an increase in $j_{||}$ at z = 1, 2, and 3 R_E as the pressure pulse impacts the magnetosphere.
- The increase in $j_{||}$ propagates with the pressure perturbation.
- The increase in $j_{||}$ is located well-inside of the magnetopause.
- The location of $j_{||}$ corresponds to the region where contours of V and pV^g intersect and this favors the theory that field-aligned current is generated by changes in flux tube volume and pressure.

References

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