Recirculation of Plasmasphere Material During a Storm Time Event

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Abstract

The fate of Plasmasphere material once it is drained out of the plasmasphere through a plume is unknown. One of two things may happen to the vented plasmasphere material. It can be either swept away with the solar wind, lost to the earth system, or it may be recirculated into the magnetosphere system, either through the low latitude boundary layer or over the poles and through the mantle. Recirculating plasmasphere material could plausibly enter the central plasma sheet and contribute to the ring current. Using observations to study the fate of the plasmasphere material is difficult as it is mostly hydrogen and becomes homogenized with solar wind hydrogen once it passes through the day side magnetopause. Numerical models, however, can keep the material distinct, opening the possibility of resolving the question using simulations. This work seeks to answer the question, does any plasmasphere material recirculate back into the magnetosphere? This is done by studying simulations produced by the Space Weather Modeling Framework (SWMF) configured to couple three models: the Block Adaptive Tree Solar Roe Up Wind Scheme (BATS-R-US) model, the Dynamic Global Core Plasma Model (DGCPM) plasmasphere model, and the Ridley Ionosphere Model (RIM). For this simulation BATS-R-US is configured to use two fluids. The first fluid represents currently accepted sources of ring current material, namely the solar wind and high latitude ionospheric outflow. The second fluid represents the plasmasphere. Within 10 Earth Radii (RE) the dynamics in BATS-R-US on closed field lines are dictated by coupling with the DGCPM. DGCPM passes the density of material in the plasmasphere to BATS-R-US. In addition to this coupling, RIM passes electric field information to both BATS-R-US and DGPCM while receiving current density form BATS-R-US. The outputs of the simulation are examined to evaluate plume recirculation. The fate of the plasmasphere material is then studied in an idealized.

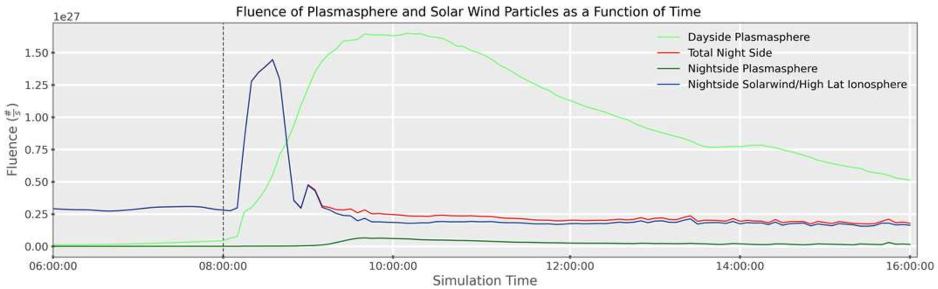
Key question: *Is Recirculated Plasmasphere Material a significant contributor to material being injected onto the nightside through the plasma sheet?*

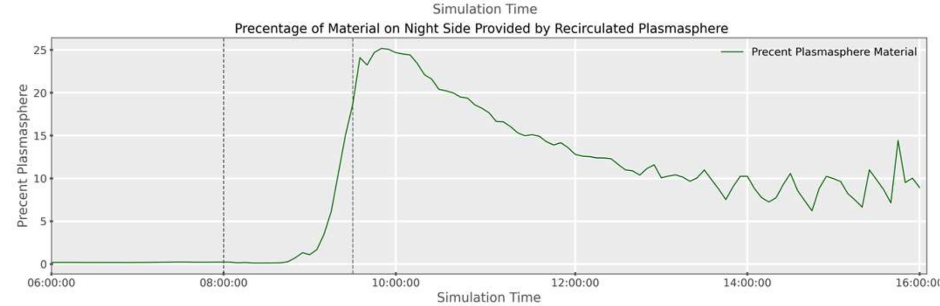
Method: Simulation of Storm with dayside plume using the SWMF with MHD-Plasmasphere coupling.

Storm: Constant Solar Wind density and velocity: 5*cm*$^{-3}$, 450*km/s*. 8 hours northward IMF, followed by 8 hours of southward IMF (slight B_y tilt of +2 nT)

Metrics

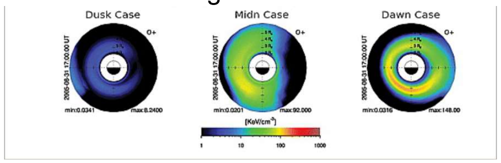
Fluence: Recirculated Plasmasphere Material is an order of magnitude less then what leaves the Plasmasphere on the dayside. However, it is on the same order as the Fluence of Solar Wind Material on the nightside.



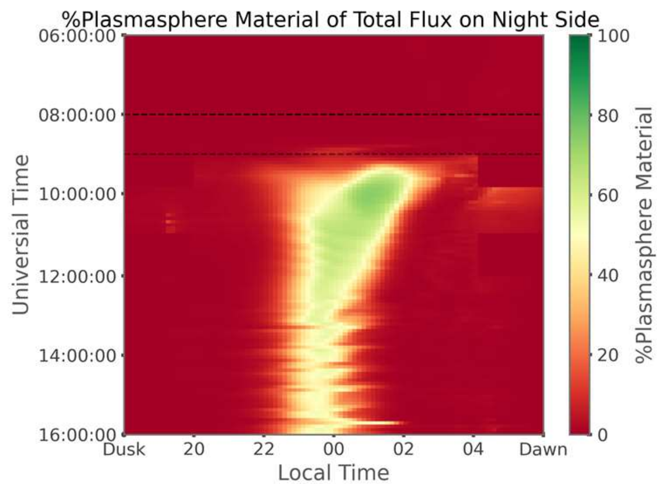


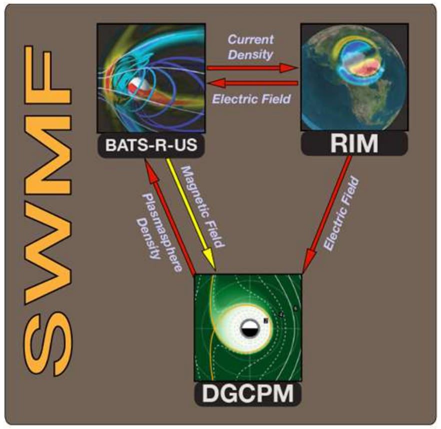
%Fluence: While the Plasmasphere is dense, Recirculated Plasma makes up a significant portion of the material accreted onto the nightside. When the Plasmasphere is less dense, the contribution drops, but remains at non-negligible levels.

From Welling et al. 2011: Oxygen was injected in a local time window centered around dusk, midnight, and dawn. The location in which material is injected effects how much remains in the ring current.[1]



Percent Plasmasphere Material Flux by Local Time: The Contribution of Recirculated Material happens in a relatively local region, slightly dawnward of midnight.





Conclusion and Future Work: *Recirculated Plasma is a non-negligible, possibly significant, source of material being accreted onto the night side through the plasma sheet in the SWMF.* Further work is needed to see if this is a real phenomena, requiring observation of real-world events. In addition, work is needed to determine how the ring current and Plasmasphere are affected by this recirculation.

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1.) Welling, D. T., Jordanova, V. K., Zaharia, S. G., Glocer, A., and Toth, G. (2011), The effects of dynamic ionospheric outflow on the ring current, *J. Geophys. Res.*, 116, A00J19

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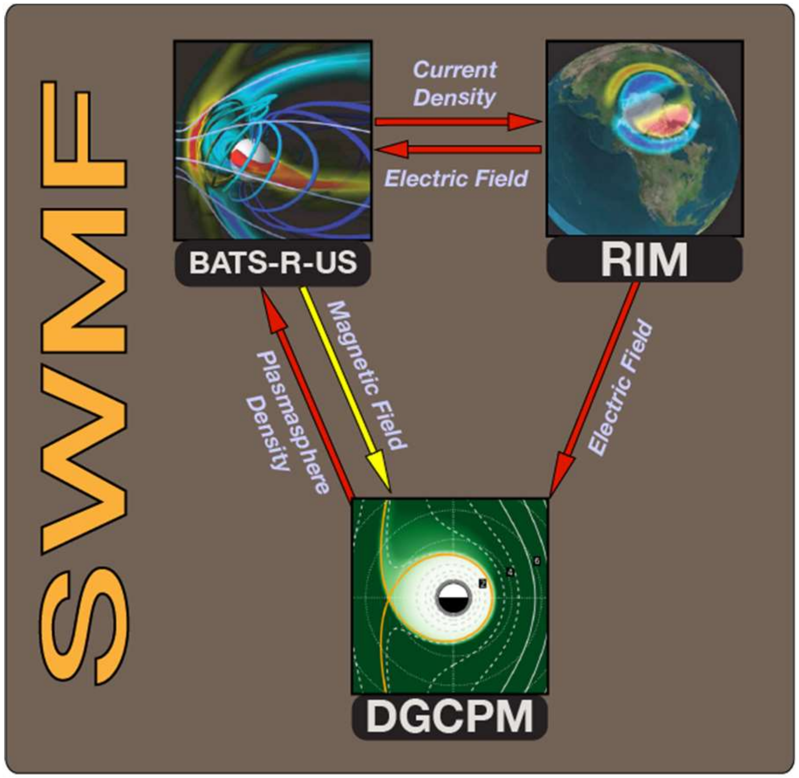
Introduction

Key Question: Is Recirculated Plasmasphere Material a significant contributor to material being injected onto the nightside through the plasma sheet?

Currently: Plasmasphere material is considered while in the Plasmasphere region. Represented by the Dynamic Global Core Plasma Model (DGCPM) passing Plasmasphere Density to the Block Adaptive Tree Solar-wind Roe Upwind Scheme (BATS-R-US). While the fluid remains in the simulation, Plasmasphere material isn't treated as a source in any of the equations regulating regions where the Plasmasphere material may end up, such as the Ring Current.

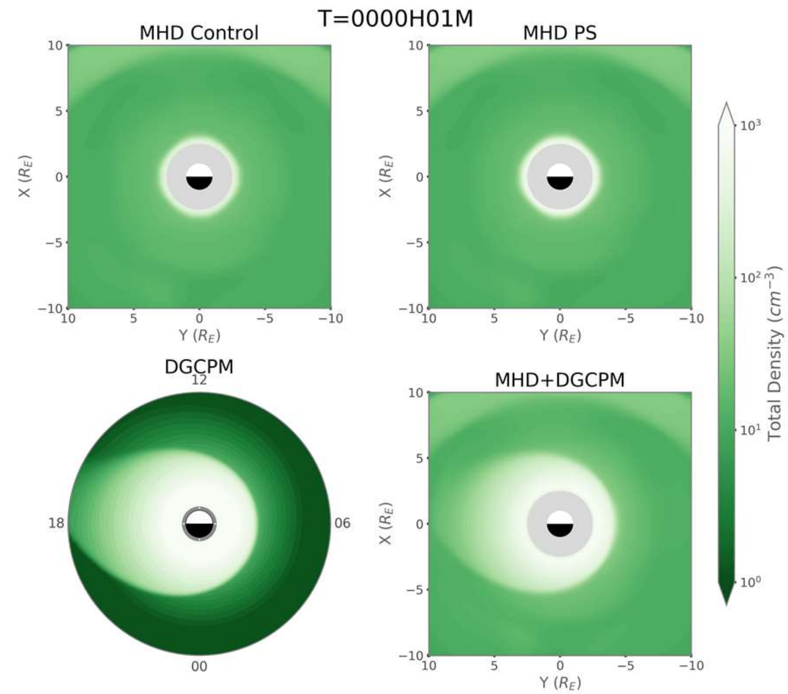


The Space Weather Modeling Framework (SWMF) couples codes designed to handle specific elements of the space environment. BATS-R-US is a multi-fluid magnetohydrodynamic (MHD) code. While any number of fluids can be utilized, we choose two fluids: the first fluid implemented represents Solar Wind and High Latitude Ionospheric outflow. The second is a dedicated Plasmasphere fluid. DGCPM is a Plasmasphere code whose inner / outer boundaries are set to 1 Earth Radii (RE)and 10 Earth Radii.

Introduction

Key Question: Is Recirculated Plasmasphere Material a significant contributor to material being injected onto the nightside through the plasma sheet?

As shown coupling BATS-R-US and DGCPM produces a much more robust and clearer Plasmasphere in the region of interest, making studying the Plasmasphere and its effects much easier.



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Experimental Setup

Plan: By using the SWMF with MHD-Plasmasphere coupling to simulate a storm event with a dayside plume, we intend to study the population of Plasmasphere material as it evolves throughout the simulation. Specifically, if the Plasmasphere Material recirculates into the nightside Plasmasphere and becomes a significant contributor to material coming into the nightside ring current and Plasmasphere.

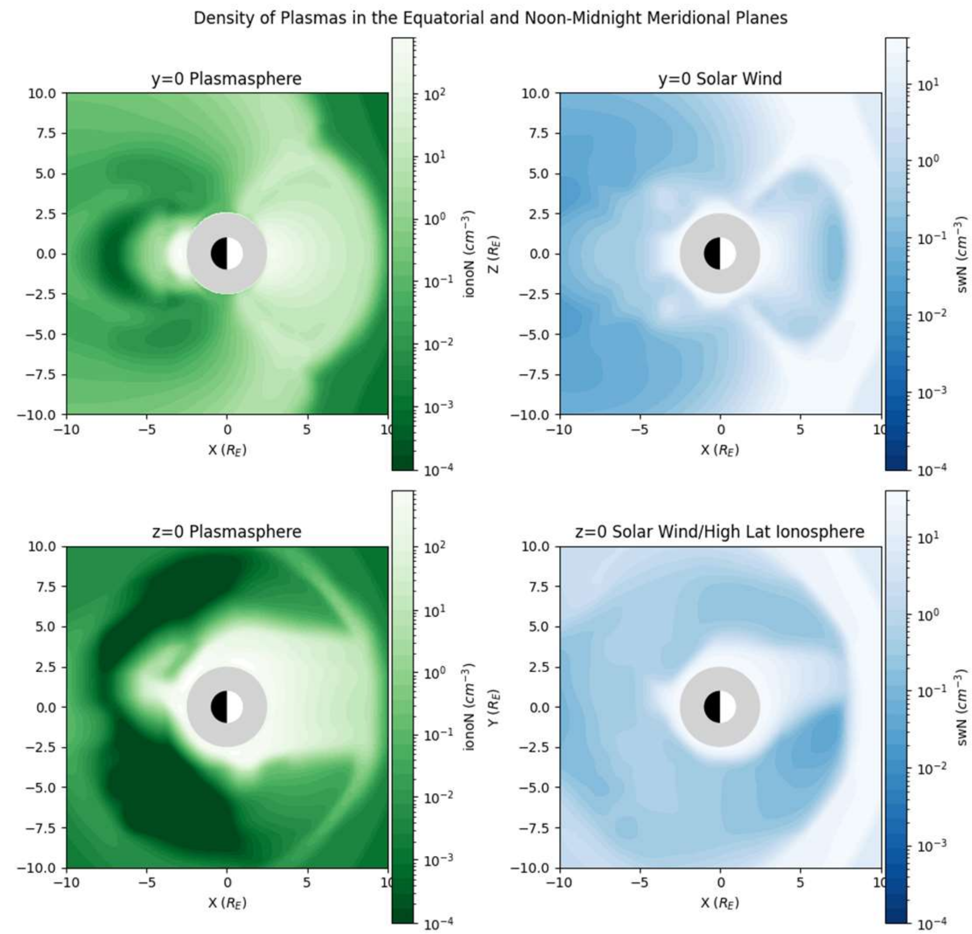
Simulation: Constant Solar Wind density and velocity: $5cm^{-3}$, $450km/s$
8 hours 5 nT northward IMF followed by 8 hours 10 nT of southward IMF (slight B_y tilt of +2 nT)

Number Density of Plasmasphere and Solar Wind Fluids in Primary Planes

All plots on the right are 2d slices from the simulation space. Z = 0 being the equatorial plane. Y=0 being the plane of the noon and midnight meridian.

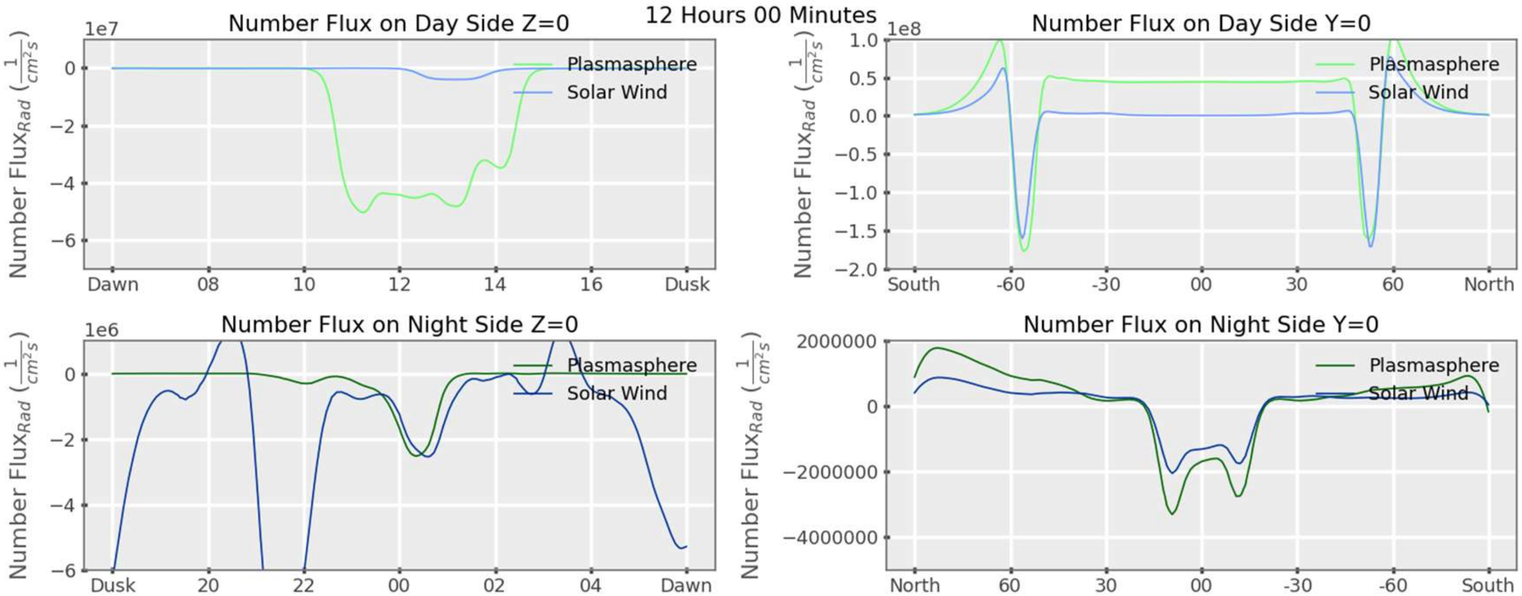
The plots clearly show the shape of the Magnetosphere and Plasmasphere helping us understand what is happening in the simulation and when it happens.

The plots show the storm produces a strong and clear plasma plume on the dayside. The night side shows there is movement of material in the tail.



Flux in Primary Planes Extraction

Flux calculated along a semi-circle of 10 RE on the nightside and 6.6 RE on the day side in the Z = 0 and Y = 0 planes.



Flux is calculated as the radial velocity times the number density

$$u_r = u_x \cos(\varphi) + u_y \sin(\varphi)$$

$$flux_r = u_r * N$$

All plots qualitatively show the relative strength of the flux in the primary planes between the two fluids. Plots show the scale of Plasmasphere material that recirculates by comparing the Flux out on the dayside to the flux in on the nightside. We estimate the amount of time it takes plasma to recirculate, by comparing spikes in dayside flux to spikes in night side flux.

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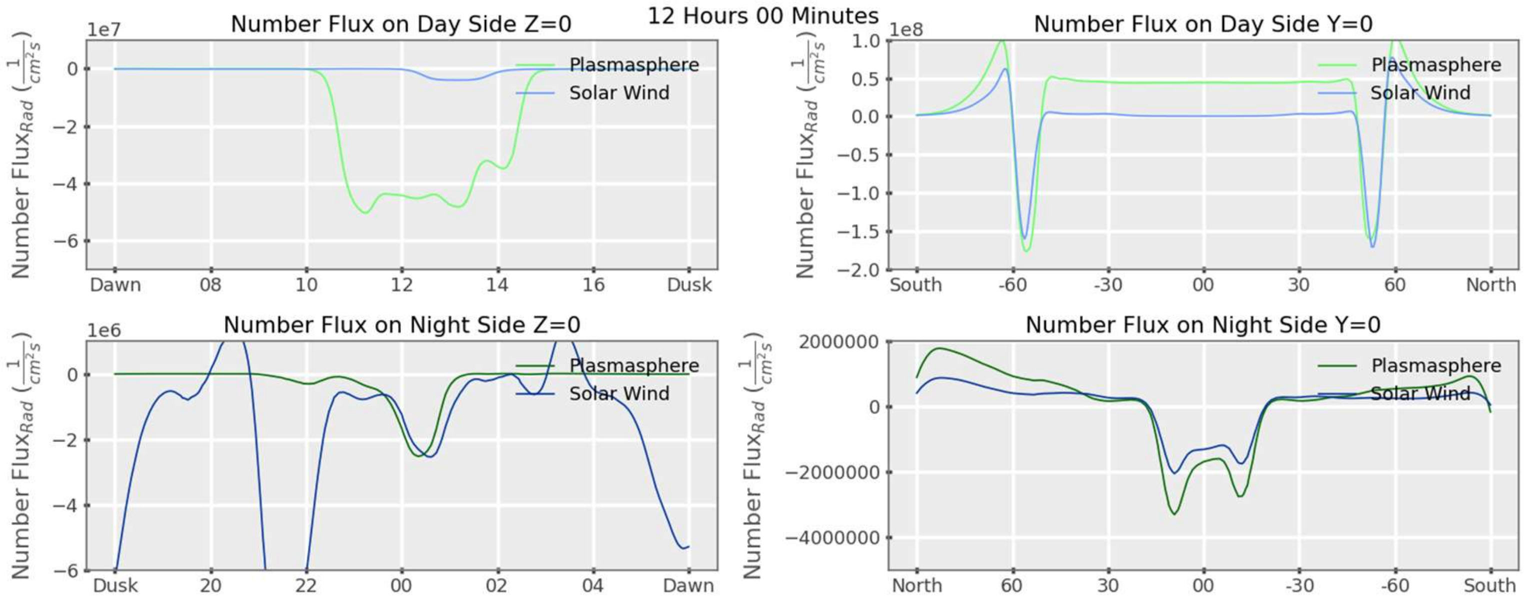


Flux is calculated as the radial velocity times the number density

$$u_r = u_x\,cos(\varphi) + u_y\,sin(\varphi)$$

$$flux_r = u_r * N$$

The order of magnitude of Recirculated Plasma is one less then that of what is vented by the dayside plume. After about 1 hr 30 min, the amount of Recirculated Plasma spikes and remains at around the same strength as the Solar Wind Flux in the Y=0 plane while being weaker in the Z=0 plane. However, the recirculated material is coming in more dawnward then the bulk of the Solar Wind Material. In the plot, the region roughly beginning 23 Hrs LT to dawnward is a contributor on par with Solar Wind Material, a point we will come back to.

Flux on Nightside of 10 RE Shell with Integrated Line Flux Plots.

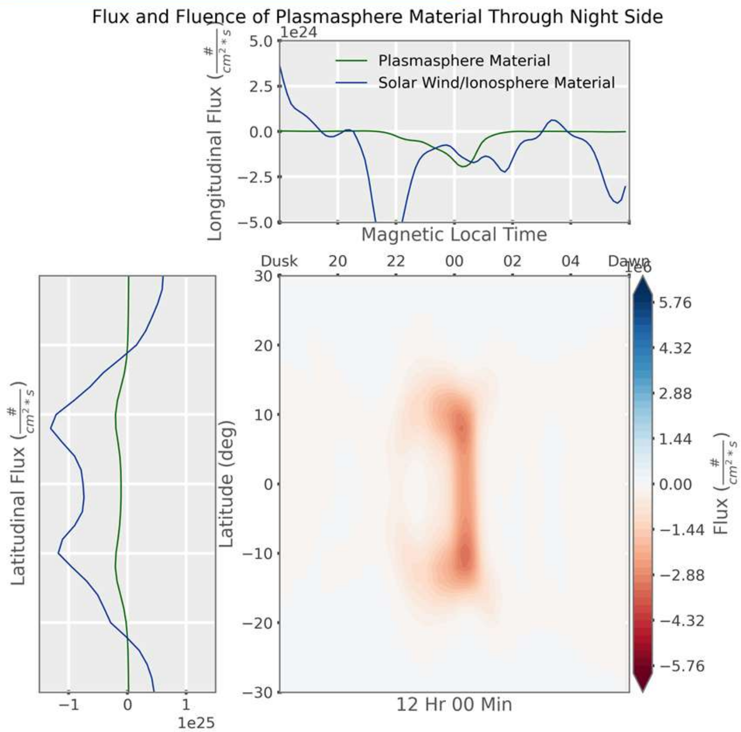
Color maps show flux of material passing through a shell of 10 RE on the nightside of the planet. Line plots show the total flux of both fluids along a given longitude (top) or latitude (left).

$u_x = velocity\ in\ x\ direction$
$u_y = velocity\ in\ y\ direction$
$u_z = go\ on\ guess\ but\ you\ can't$
$u_r = velocity\ in\ radial\ direction$
velocity measured in cm/s

$N = Number\ Density\ of\ Fluid\ \frac{\#}{cm^3}$
$flux_r = radial\ flux\ \frac{\#}{cm^2 * s}$
$\theta = colatitude\ \varphi = longitude\ (radians)$

$$u_r = u_x \cos(\varphi) \sin(\theta) + u_y \sin(\theta) \sin(\varphi) + u_z \cos(\theta)$$

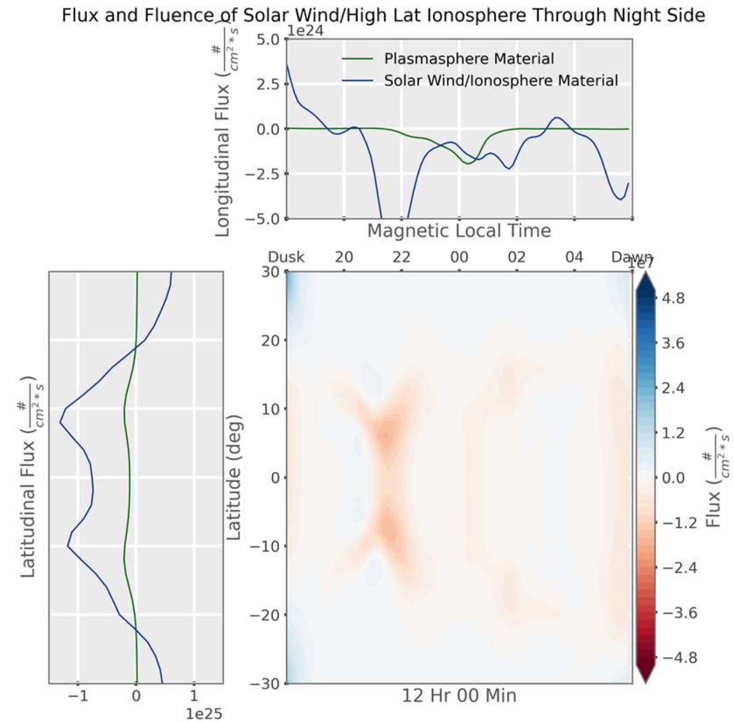
$$flux_r = u_r * N$$



Recirculated Plasmasphere Material passes through the boundary in a narrow band centered around the primary planes.

Note: the color bars have different ranges.

Solar Wind Material mostly passes through the boundary duskward of 22 Hrs LT, although a second consistent crossing is seen at 02 Hrs LT.

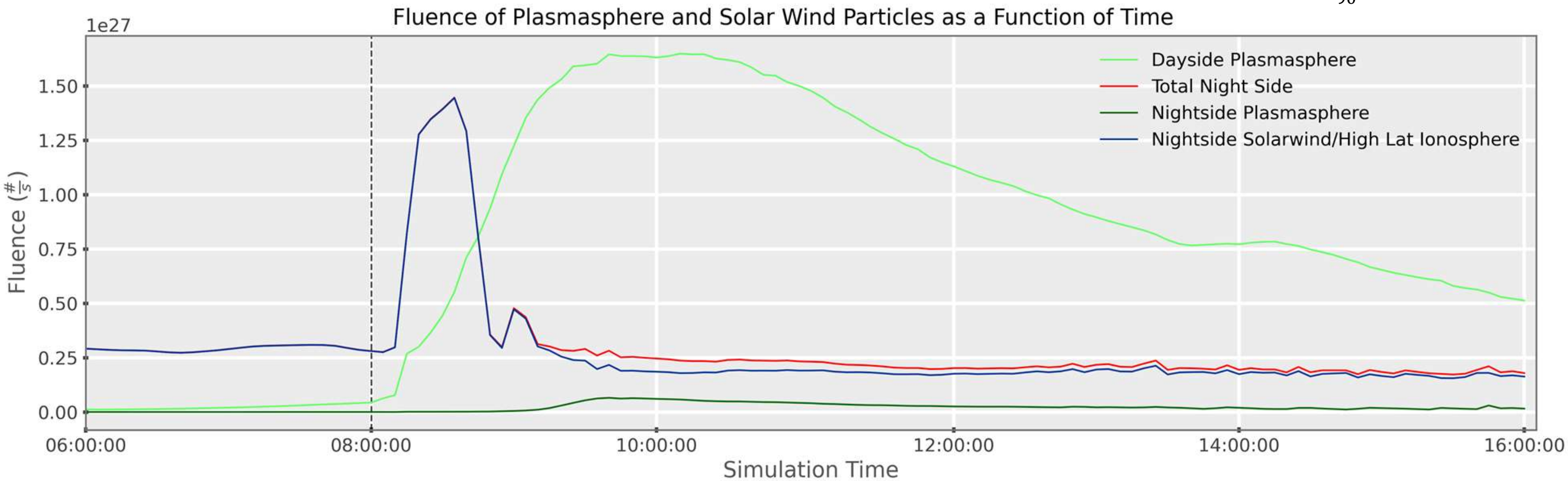


Total Fluence of Plasmasphere and Solar Wind Fluids Across Both Dayside and Nightside Boundaries.

How is it calculated: Flux integrated along longitude and latitude. Dusk to Dawn +/- 30 deg for night side. Dawn to Dusk +/- 60 deg for day side. (show equation used as result of large grid size)

$$fluence(\frac{\#}{s}) = \sum flux_r * radius^2 * cos(\theta) * d\theta * d\varphi$$

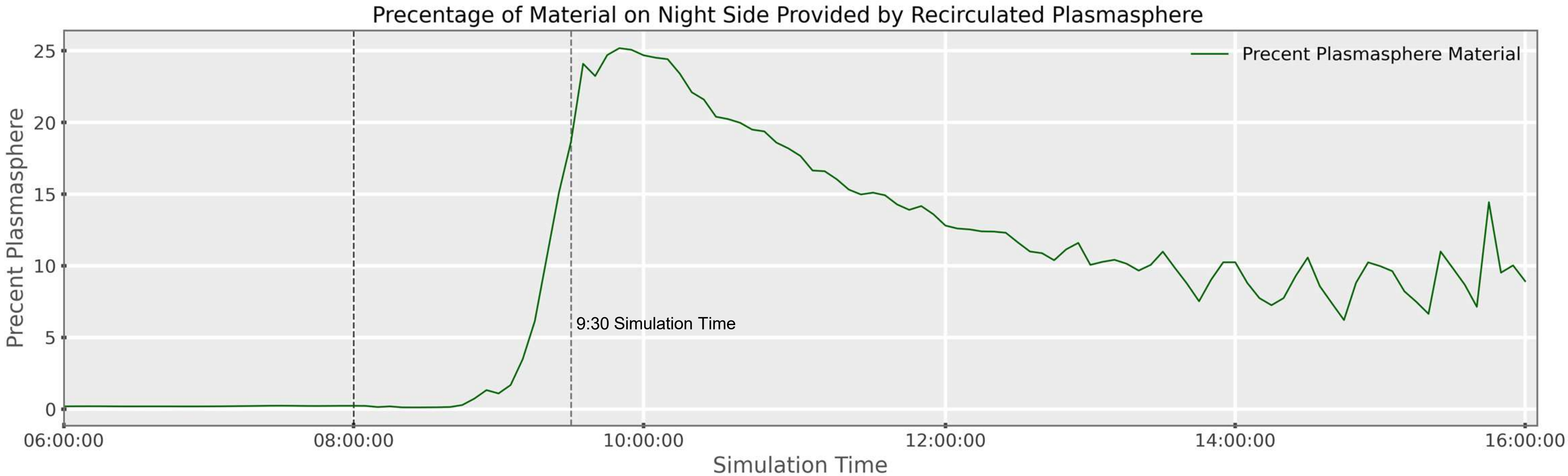
As the number of coordinate points is relatively low, we can do a summation of the 'infinitesimal' contributions directly. $d\theta = d\varphi = \frac{\pi}{90}$



- *Recirculated Plasmasphere Material is on the same order of magnitude as the Fluence of Solar Wind Material on the nightside.*
- The large spike in night side solar wind fluence shortly after the onset of the storm is the population of material built up in the tail being dumped quickly into the ring current.
- Recirculated Plasmasphere Material is an order of magnetic less then what leaves the Plasmasphere on the dayside.
- As the fluence of dayside Plasmasphere material decreases we see that the nightside Plasmasphere fluence remains relatively the same, despite the lower amount of plasma being vented at later times.

Percentage of Total Fluence on Nightside Provided by Recirculated Plasmasphere Material

- *While the Plasmasphere plume is broad and dense, Recirculated Plasma makes up to 25% of all material crossing the nightside 10 RE boundary.*
- When the Plasmasphere plume is less dense, the contribution drops while remaining at non-negligible levels.



Percentage Plasmasphere is calculated as the ratio of Nightside Plasmasphere Fluence to Total Nightside Fluence.

Percent Contribution of Recirculated Plasmasphere Material by Local Time.

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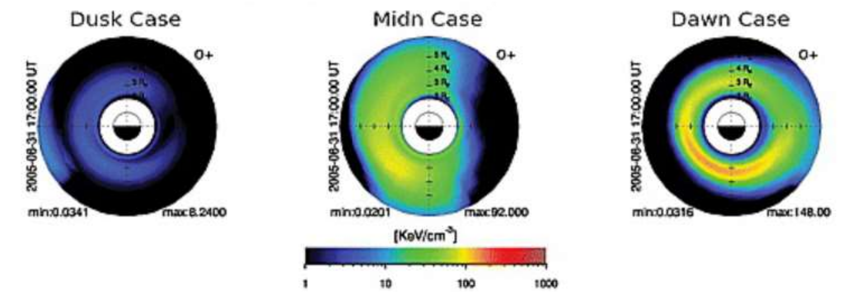
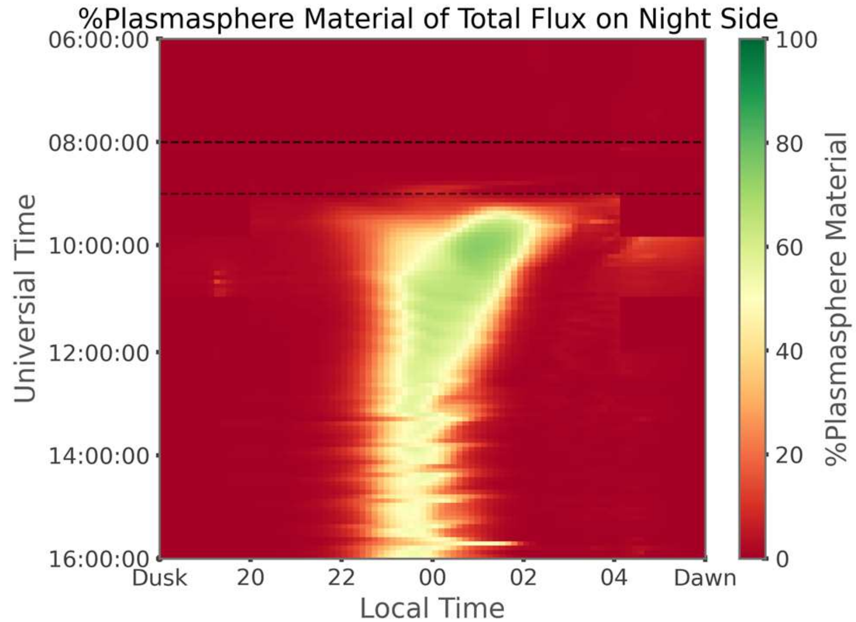


Flux is summed along degrees of constant longitude between +/- 30 degrees latitude. For every box along LT, the flux of the Plasmasphere is compared to the total flux of all material and a simple percentage calculated.

Dawnward of 22 Hrs Recirculated Plasmasphere Material makes up a large if not dominant percentage of the total flux of particles across the nightside boundary. This is important because, as shown by Welling 2011, the more dawnward material is injected into the ring current the more likely the material is to remain in the ring current on closed drift paths.

Relative strength of contribution of Recirculated Plasmasphere Material to the total flux of all material crossing the nightside boundary along the local time axis.



The Contribution of Recirculated Material happens in a relatively local region, slightly dawnward of midnight.

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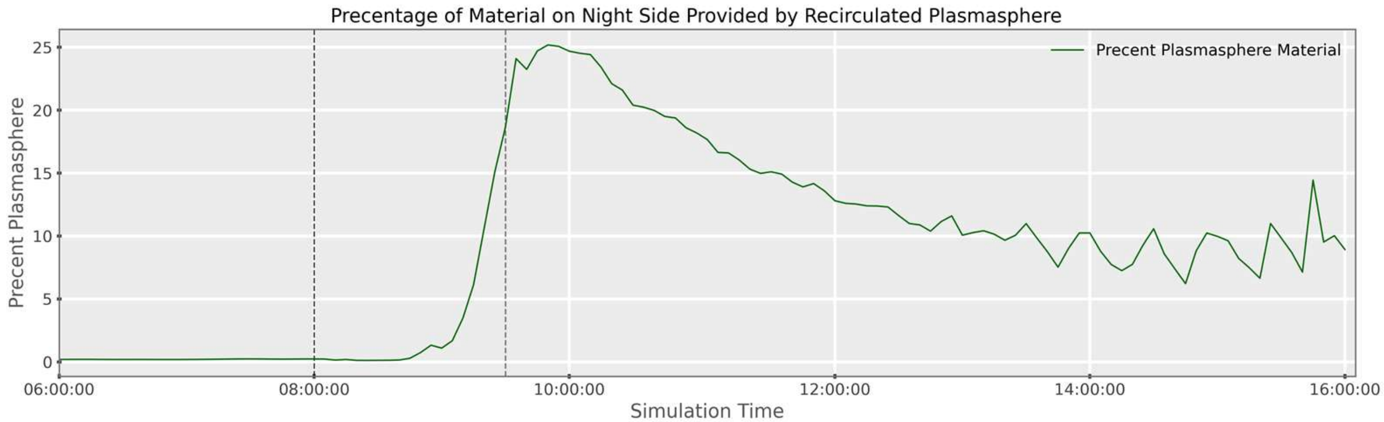
Conclusions

Recirculated Plasma is a non-negligible, possibly significant, source of material being accreted onto the Nightside through the plasma sheet in the SWMF.



Future Work

While our initial look is tantalizing, there is still a lot of work to do! Immediate follow-up questions include:

1. What is the percent of Plasmasphere Origin Material that recirculates.
2. Flow trace of Plasmasphere Material as it goes from plume to nightside.
3. How much recirculated material contributes to the ring current after crossing the nightside boundary, i.e. doesn't enter the ring current on an open drift path, but one closed around the earth.
4. How does storm strength effect recirculation, i.e. if the storm is too strong does the Plasmasphere Material get swept away? If it is to weak, is the Plasmasphere Material not able to recirculate?
5. Distribution of velocity for Plasmasphere Material that recirculates. (particle tracing)
6. If Plasmasphere Material is treated as a source of material in the ring current, such as solar wind and high latitude ionospheric outflow are, how does that change simulations both with and without a strong plume?

While it seems likely that recirculated material is non-negligible in the model, work is needed to see if this is a real phenomena requiring observation of real-world events.