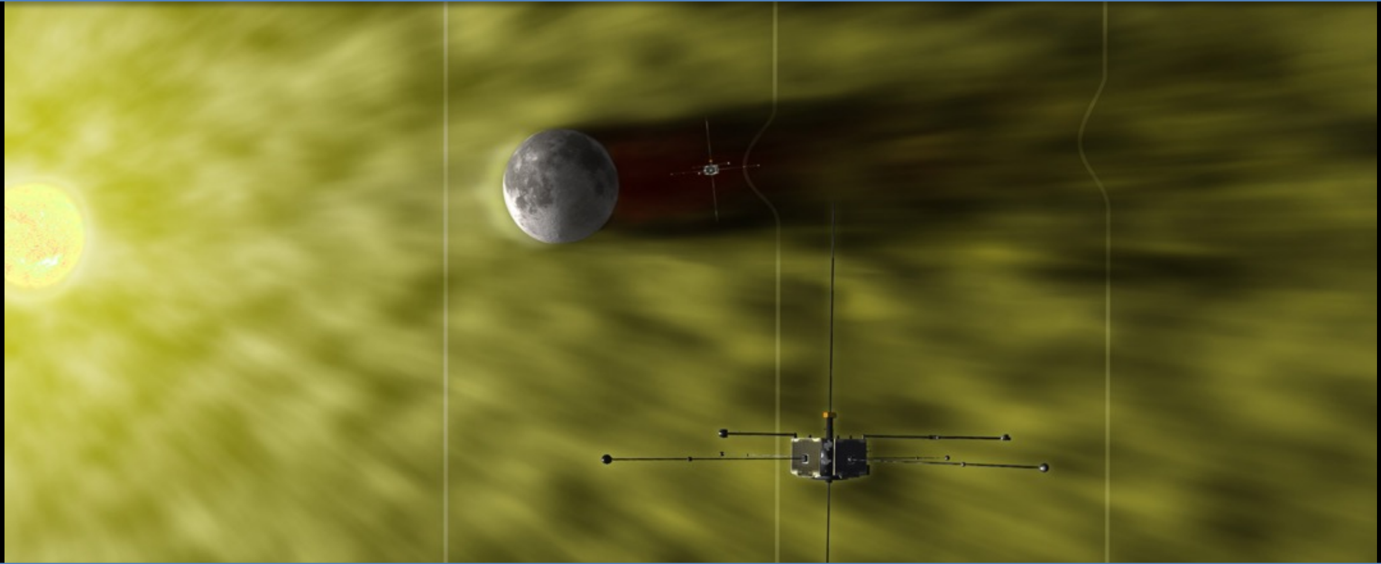

Time-Dependent Hybrid Plasma Simulations of Lunar Electromagnetic Induction in the Solar Wind

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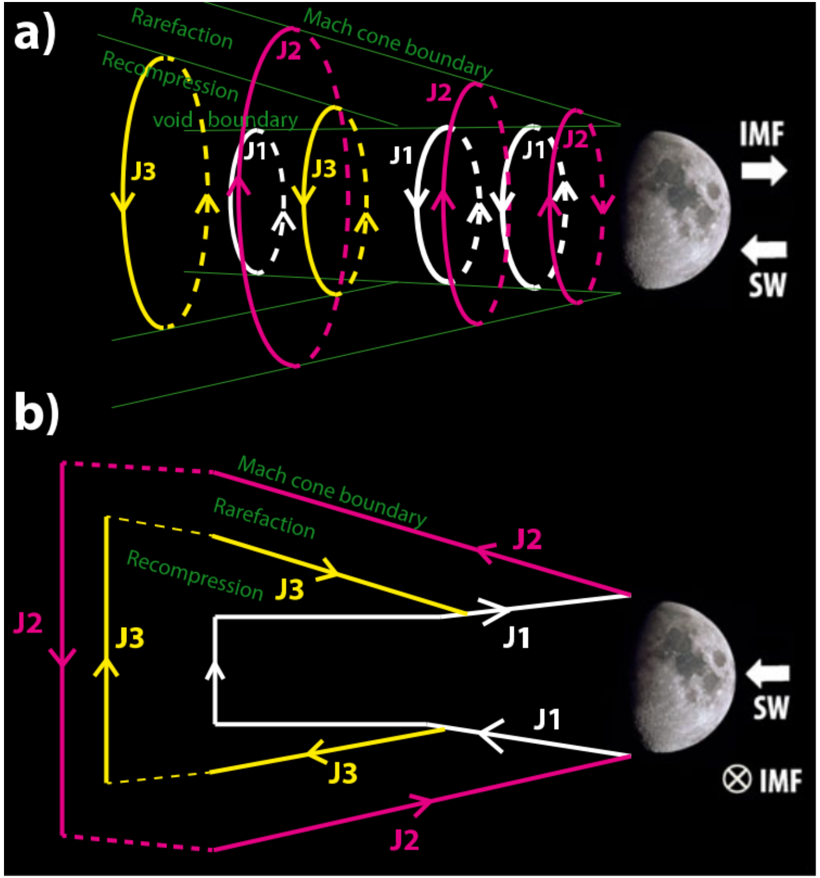
Fuqua Haviland, H., Poppe, A. R., Fatemi, S., Delory, G. T., & de Pater, I. (2019). Time-dependent hybrid plasma simulations of lunar electromagnetic induction in the solar wind. *Geophysical Research Letters* , *46*(46), 4151–4160. https://doi.org/10.1029/2018GL080523.

Fatemi, S., Fuqua, H. A., Poppe, A. R., Delory, G. T., Halekas, J. S., Farrell, W. M., Holmström, M. (2015). On the confinement of lunar induced magnetic fields. *Geophysical Research Letters*, 42(17), 6931–6938. doi:10.1002/2015GL065576.

Poppe, A. R., et al. AGU Fall Meeting 2019. P31C-3447 - ARTEMIS observations of electromagnetically induced fields from the lunar interior. Wednesday AM poster session.

Wake Current Systems



what we know:

- *wake forms on nightside due to dayside absorption and vacuum cavity*
- *wake current systems (incl. structure, extent) organize according to solar wind characteristics*

$\boldsymbol{v}_{sw}, \boldsymbol{B}_{IMF}$

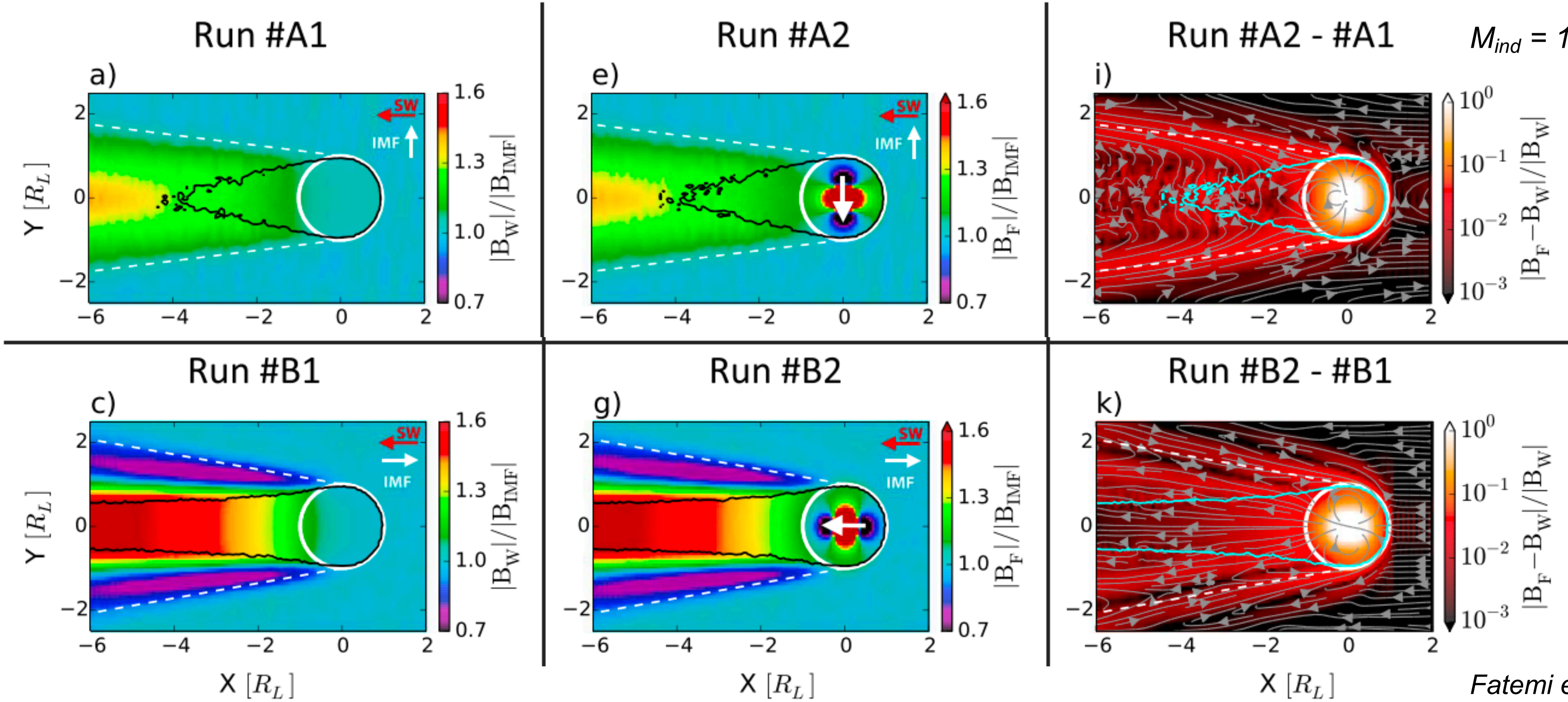
n_e, n_i

T_e, T_i

$\sigma(r)$,t *This study*

Fatemi et al., [2014]
Holmstrom et al., [2012]

Static Hybrid Model Results



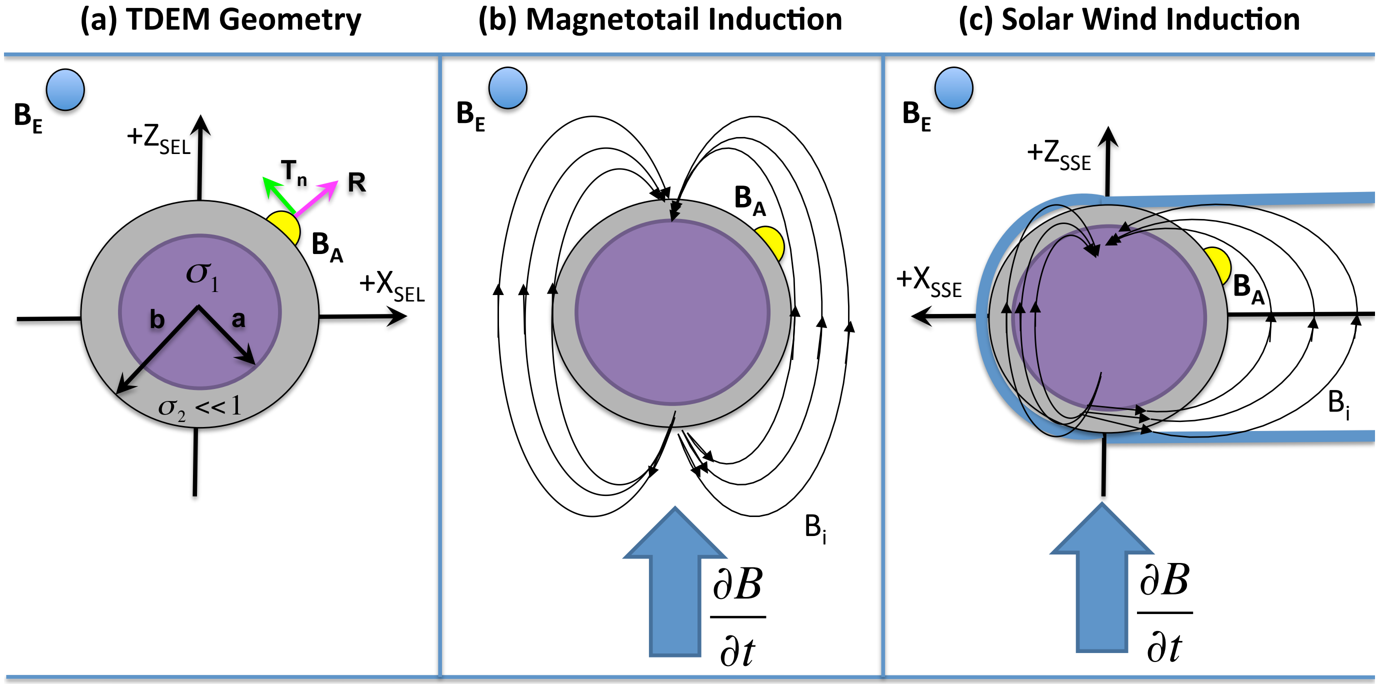
M_{ind} = 10^16 A m^2

Fatemi et al., [2015]

Dayside confinement, as predicted. Nightside fields are not confined within wake cavity. Strong induced field signatures in the deep wake near surface, especially with large IMF changes.

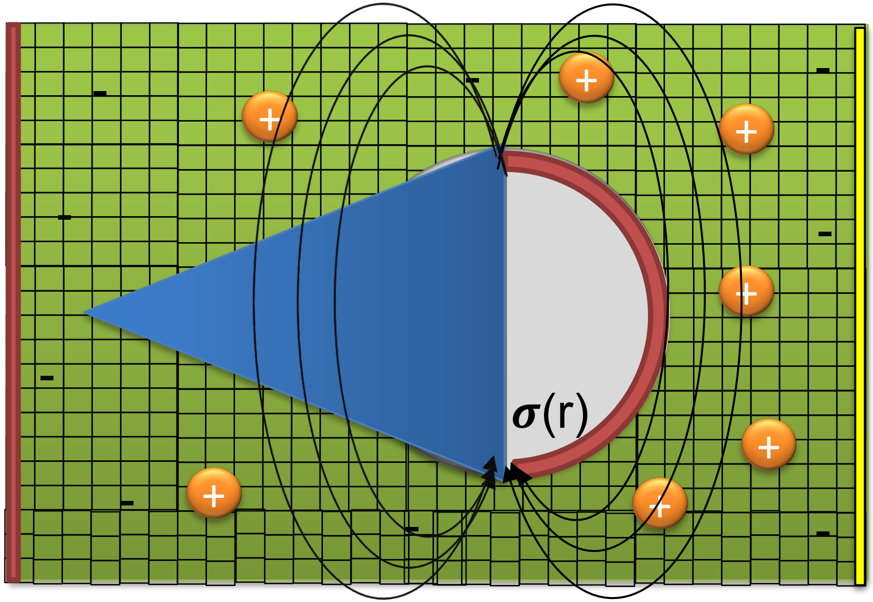
Lunar EM Sounding - Transfer Function Method

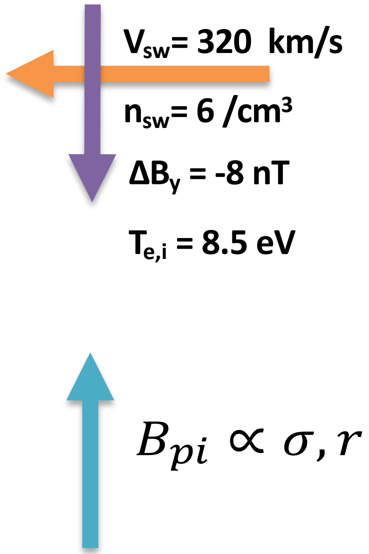
The Apollo Picture



Fuqua Haviland et al., 2019. ASR.

Transient Plasma Hybrid Kinetic Model

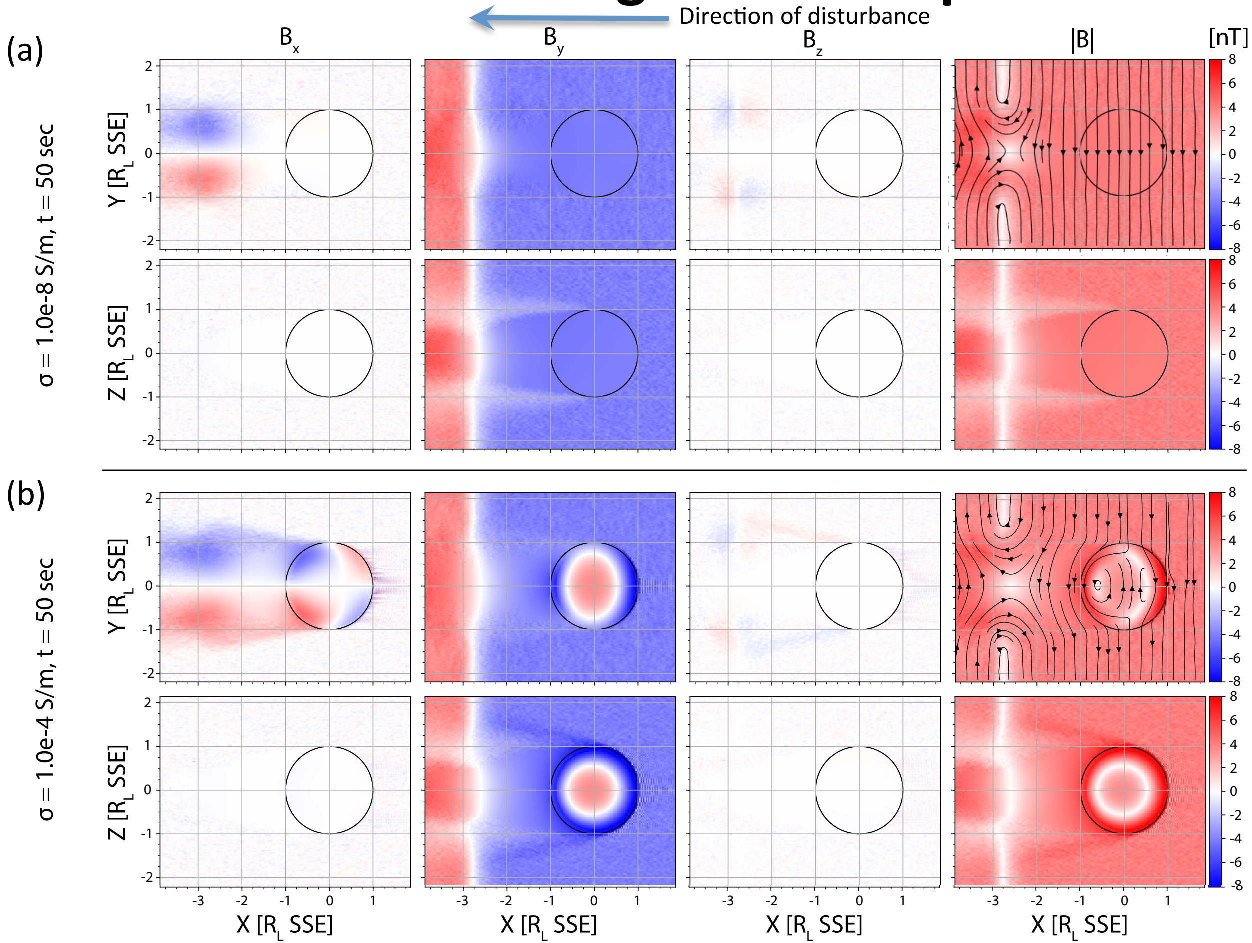


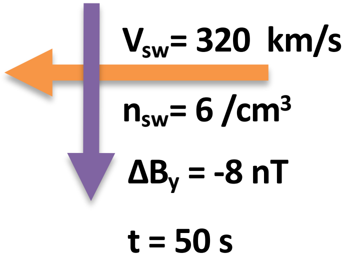


- cell size: 50 km (~0.028 RL)
- 16 macroparticles (only protons) per cell
- t_{step} = 0.001 s
- 0 < t < ~300 s, t=24 s IMF discontinuity
- σ_1 = 1.0 e – 8, 1.0 e – 4, 1.0 e – 3 [S/m]

- conducting radius (r_1) = 1,600 km (~ 0.91RM, or ~ 32 cells), ~M_{ind} = 1.64 e 17 A m^2 (Fatemi et al., 2015; Saur et al., 2010).
- resistive crust (1e-8 S/m) radius = 150 km (~3 cells crust)
- captures inductive and plasma response self-consistently

Results: Single Time Step





Fuqua Haviland et al., 2019. GRL.

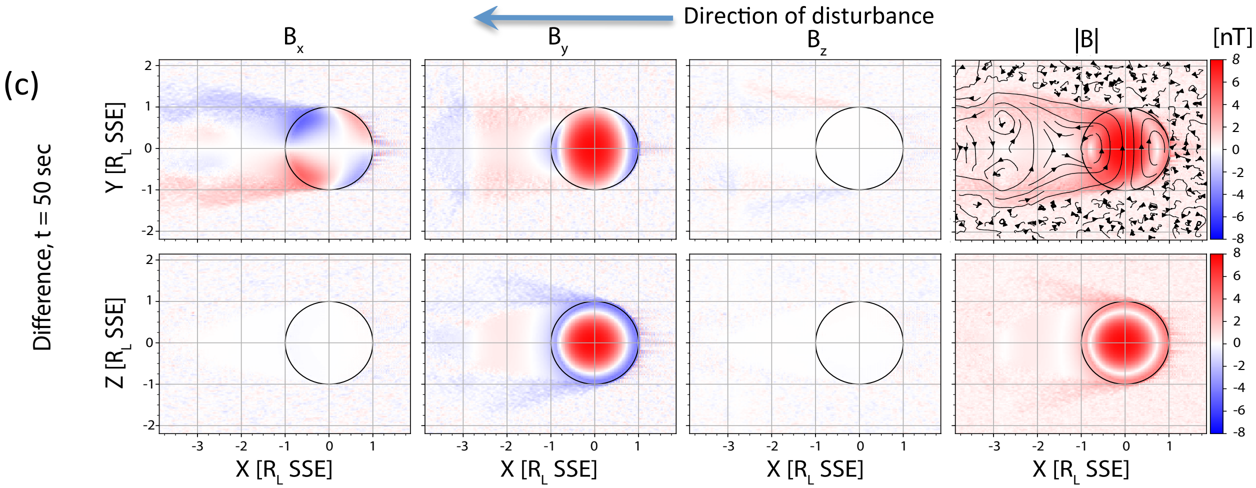
Results: Single Time Step (con't)

V_{sw}= 320 km/s

n_{sw}= 6 /cm³

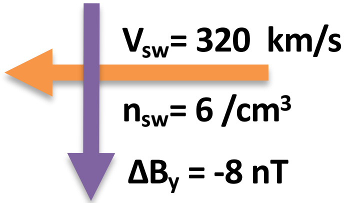
ΔB_y = -8 nT

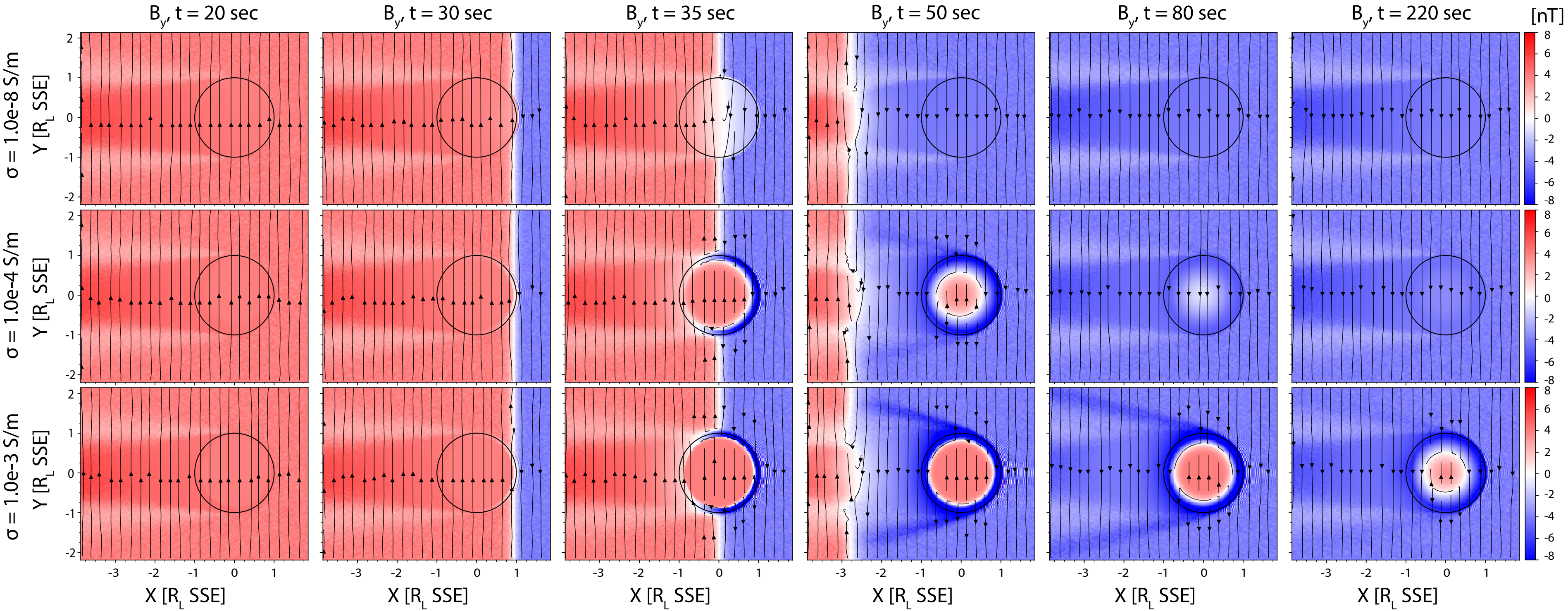
t = 50 s



Fuqua Haviland et al., 2019. GRL.

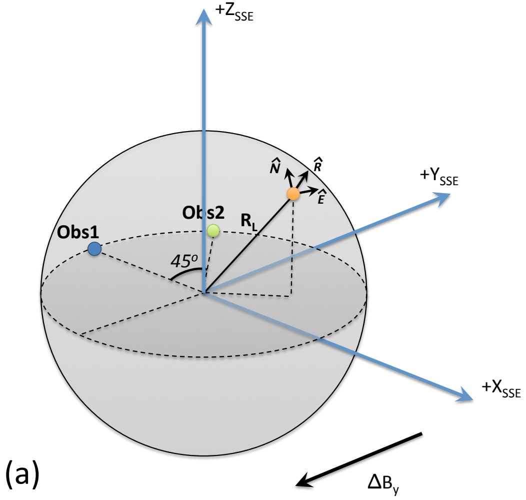
Results: Temporal effects

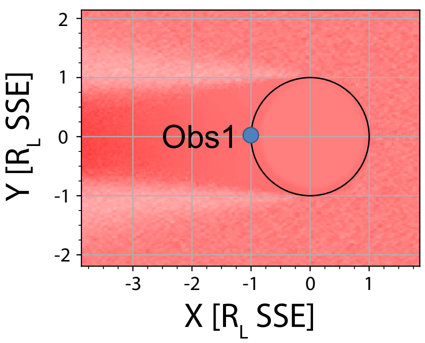




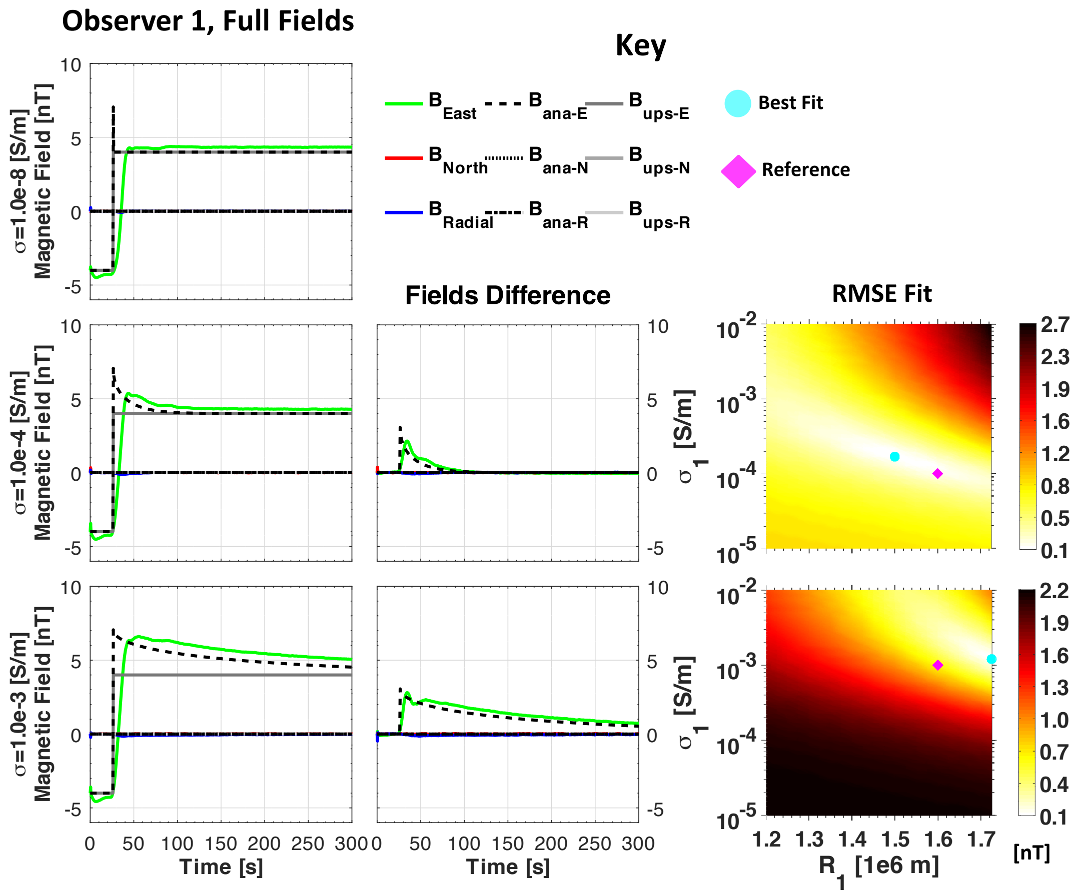
Fuqua Haviland et al., 2019. GRL.

Comparison to Analytic Theory





Fuqua Haviland et al.



Fuqua Haviland et al., 2019. GRL.

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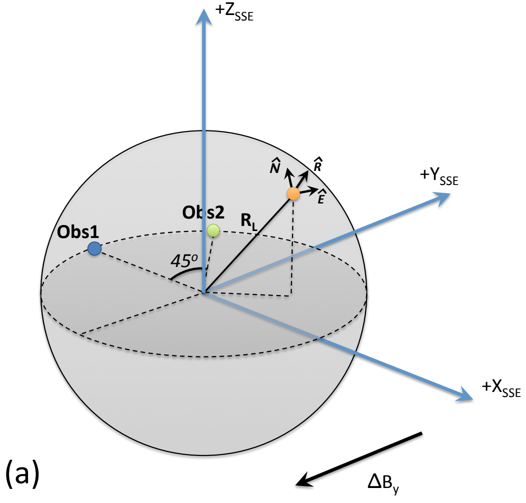

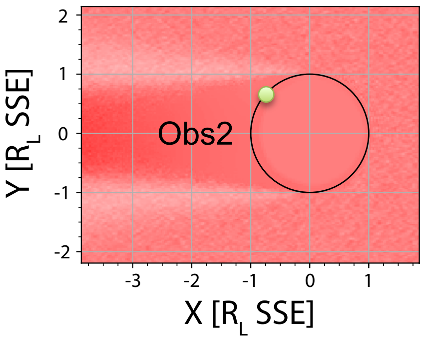

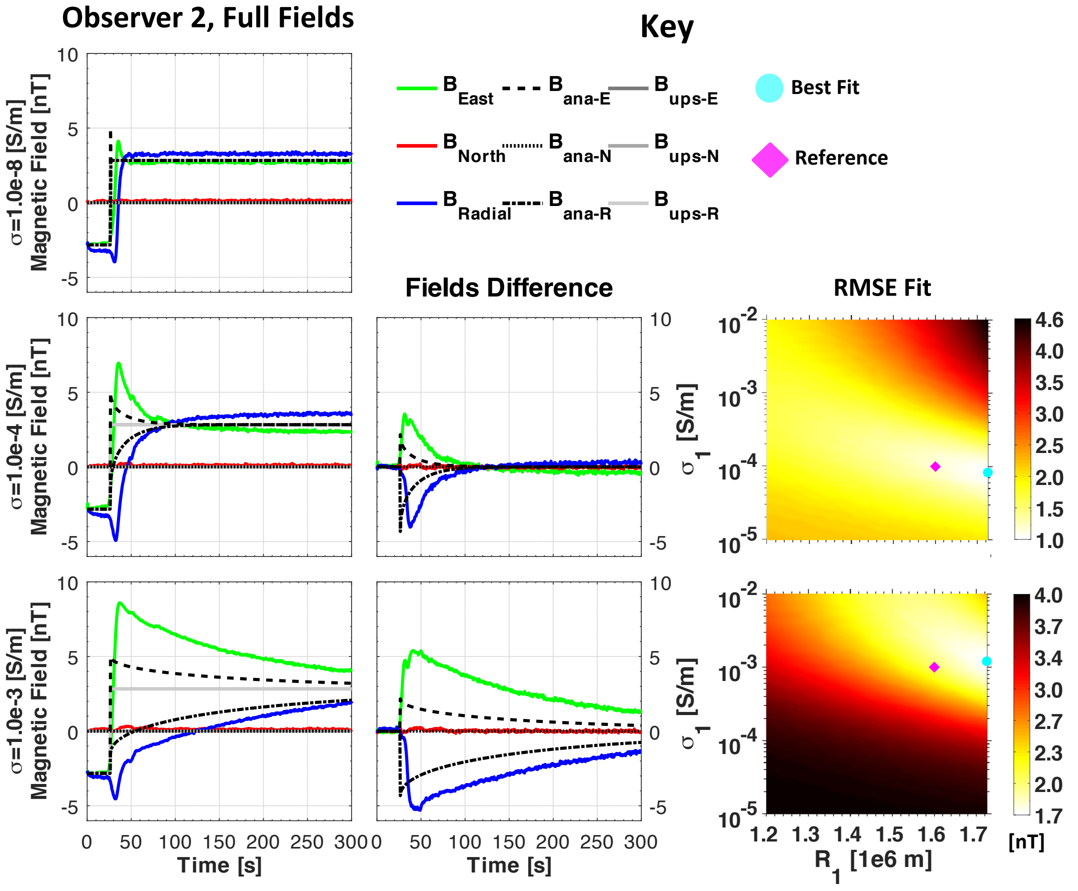

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Conclusions

- Vacuum theory alone is not able to fully characterize nightside induced fields. Some agreement on exponential time decay.
- Time-dependent plasma hybrid model is able to characterize plasma currents and induced fields which vary depending on solar wind conditions.
- Our model suggests enhanced nightside fields over theory.
  - Due to plasma-induced fields constructively add.
  - Compression of dayside induced fields at the terminator by SW ram pressure.
- Redefining Apollo era assumption about wake field confining induced field within cavity.
- We confirm that the inclusion of plasma interaction effects alongside inductive currents from a planetary interior yields results different than that from the vacuum response theory alone.

Questions?