Ring Current Plasma Pressure Reconstructed from Empirical Magnetic Field Distributions Embedded Within a Global MHD Model

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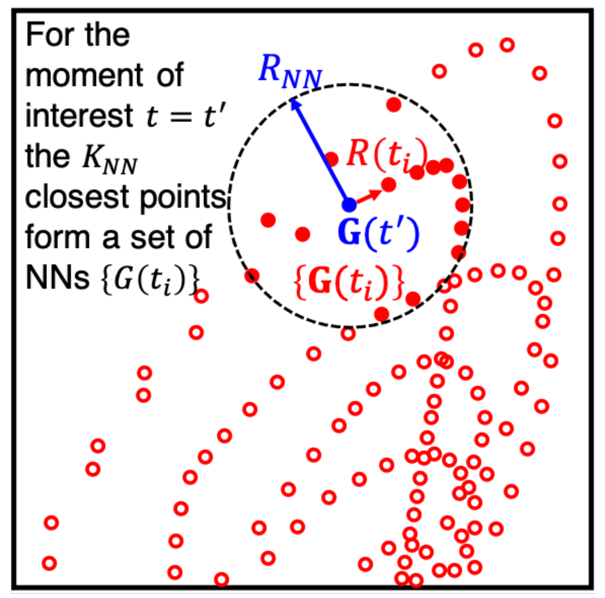
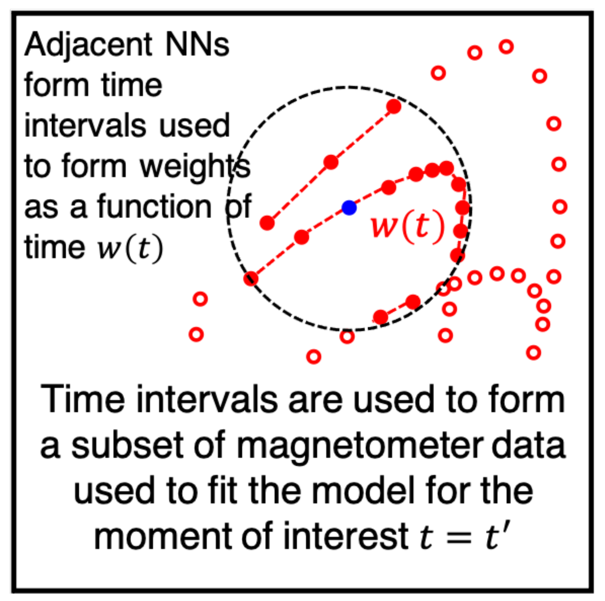
Overcoming Data Paucity via Data-mining





Not nearly enough in-situ magnetometers are in operation at any one time to adequately reconstruct the global magnetic field

To overcome this scarcity, 2x10[6] spacecraft magnetometer measurements taken across decades-worth of missions are represented in state space $G(t_i)$ parameterized by

- **Sym-H**
- **D(Sym-H)/Dt**
- $\boldsymbol{v \cdot B_z^{IMF}}$

For a given time t', K-Nearest Neighbors (KNN), where K ≈ 30,000, are selected

Each point is weighted by its distance, $R(t_i)$, from the desired state:

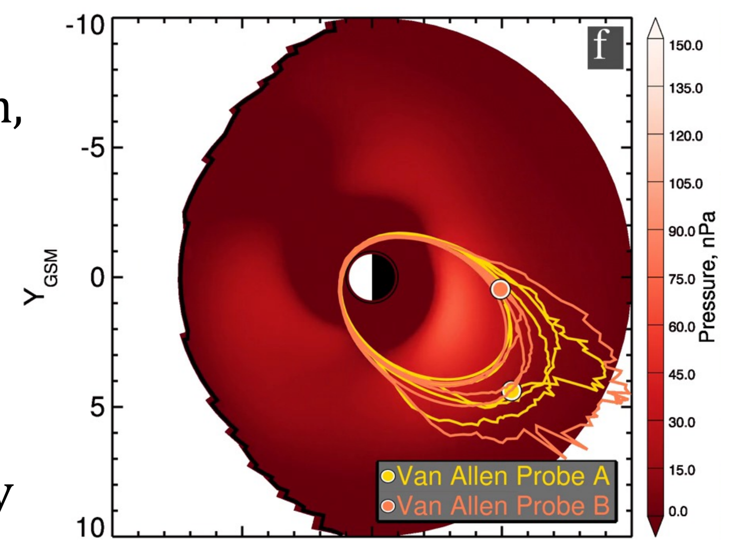
$$R(t_i) = \left(\sum_{j=1}^{3} \left(\frac{G_j(t_i) - G_j(t')}{\sigma_{G_j}} \right)^2 \right)^{\frac{1}{2}}$$

Stephens et al. (2020), *Space Weather*, 10.1029/2020SW002583
Sitnov et al. (2008), JGR, 10.1029/2007JA013003
Tsyganenko et al. (2007), JGR, 10.1029/2007JA012260

Deriving the Global Pressure

Assuming quasi-static equilibrium,

$$\vec{J} \times \vec{B} = \nabla p$$



Assuming isotropy along field lines,

$$p(r) - p(r_0) = \int_C \left(\vec{J} \times \vec{B} \right) dr'$$

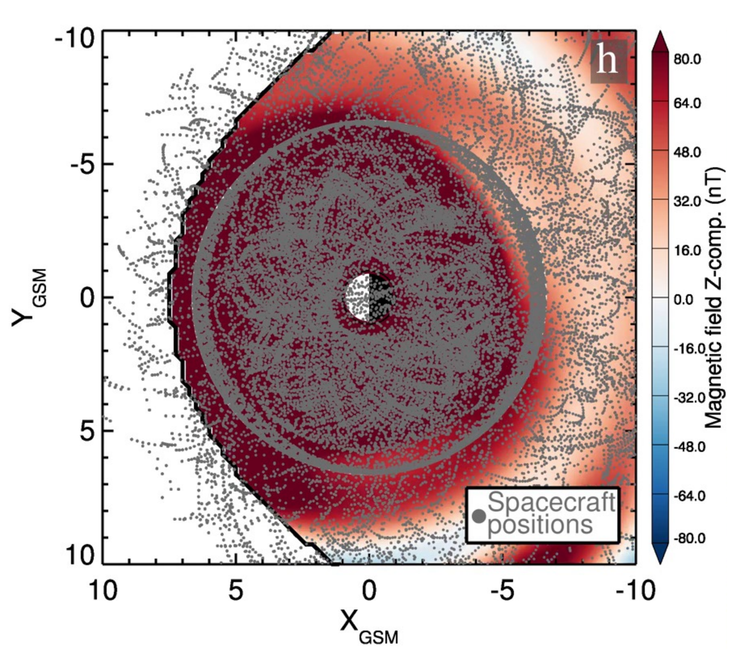
in the equatorial plane, where $p(r_0) = 0$ along outer boundary

Future work: Instead solve the Poisson-like form:

$$\nabla \left(\vec{J} \times \vec{B} \right) = \nabla^2 p$$

Stephens et al. (2020), *Space Weather*, 10.1029/2020SW002583

Reconstructing the Global Magnetic Field



KNN method produces spatial distribution of magnetometer values

These are used to fit an analytic expression of the global magnetic field

(This the methodology used in the TS07D model)

Earth's internal field

$$\vec{B}_{tot} = \vec{B}_{int} + \vec{B}_{ext}$$

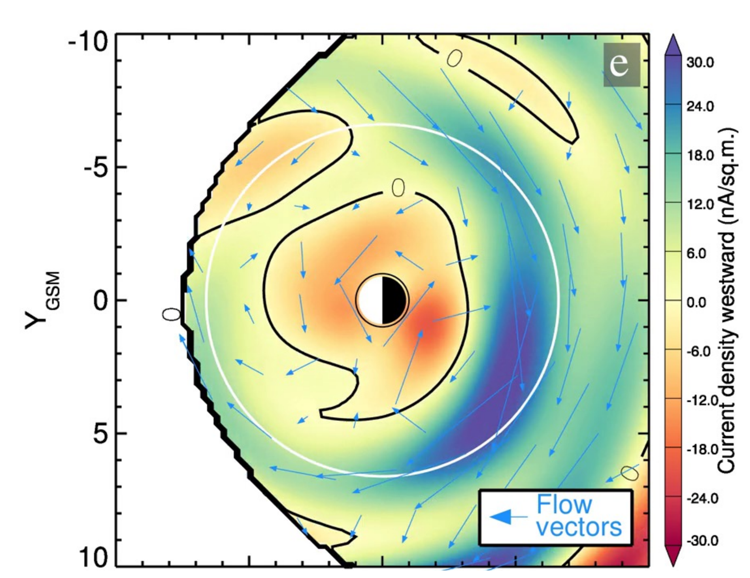
Magnetopause boundary (Shue 1998 model)

$$\vec{B}_{ext} = \vec{B}_{eq} + \vec{B}_{FAC} + \vec{B}_{MP}$$

$$\vec{B}_{eq} = \sum_{n=1}^{N} a_{0n}^{(s)} \vec{B}_{0n}^{(s)} + \sum_{m=1}^{M} \sum_{n=1}^{N} \left(a_{mn}^{(o)} \vec{B}_{mn}^{(o)} + a_{mn}^{(e)} \vec{B}_{mn}^{(e)} \right)$$

m,n: azimuthal and radial expansions
M,N: 3,20
a: Amplitude coefficients to fit with magnetometer distribution
$\vec{B}_{0n}^{(s)}, \vec{B}_{mn}^{(o)}, \vec{B}_{mn}^{(e)}$: basis functions

$\vec{B}_{FAC}$: Contribution from field-aligned currents, similar expansion to $\vec{B}_{eq}$

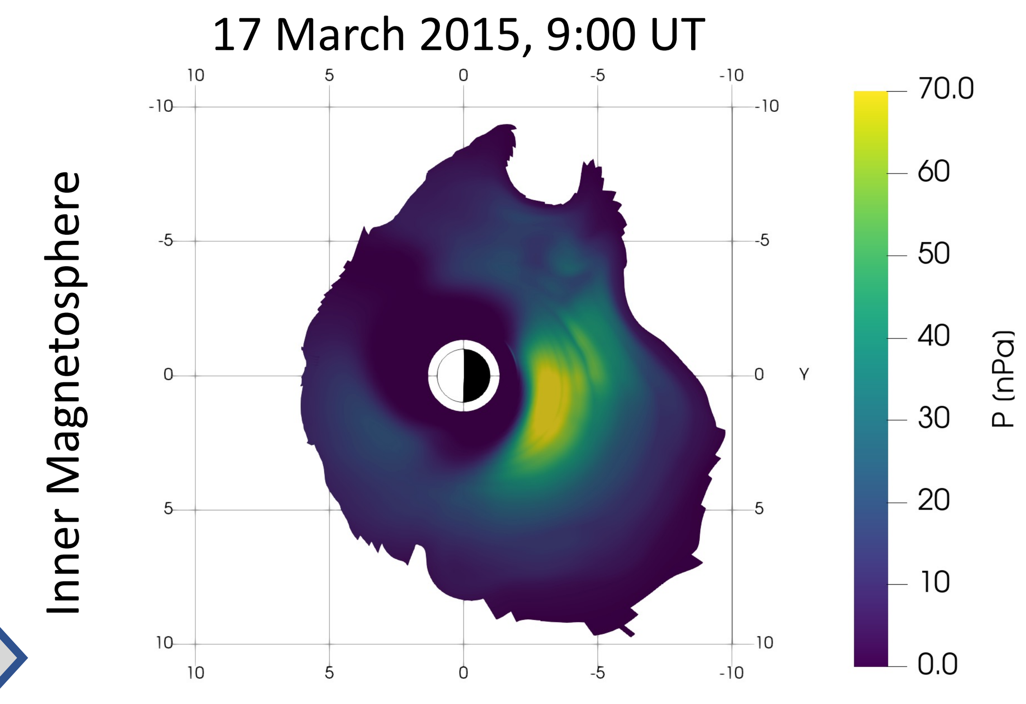


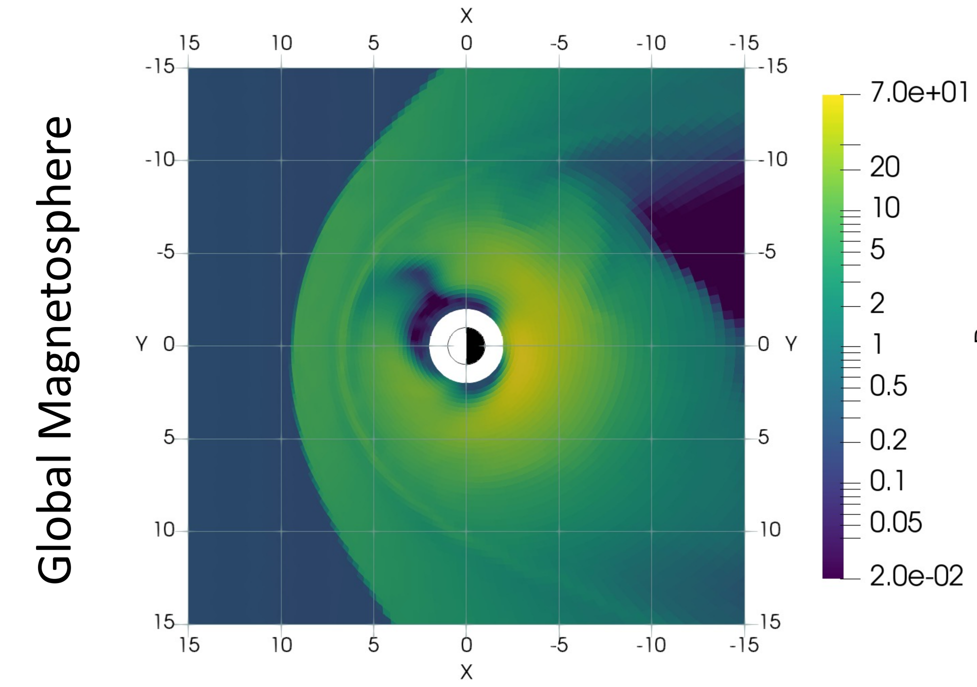
Current density obtained via

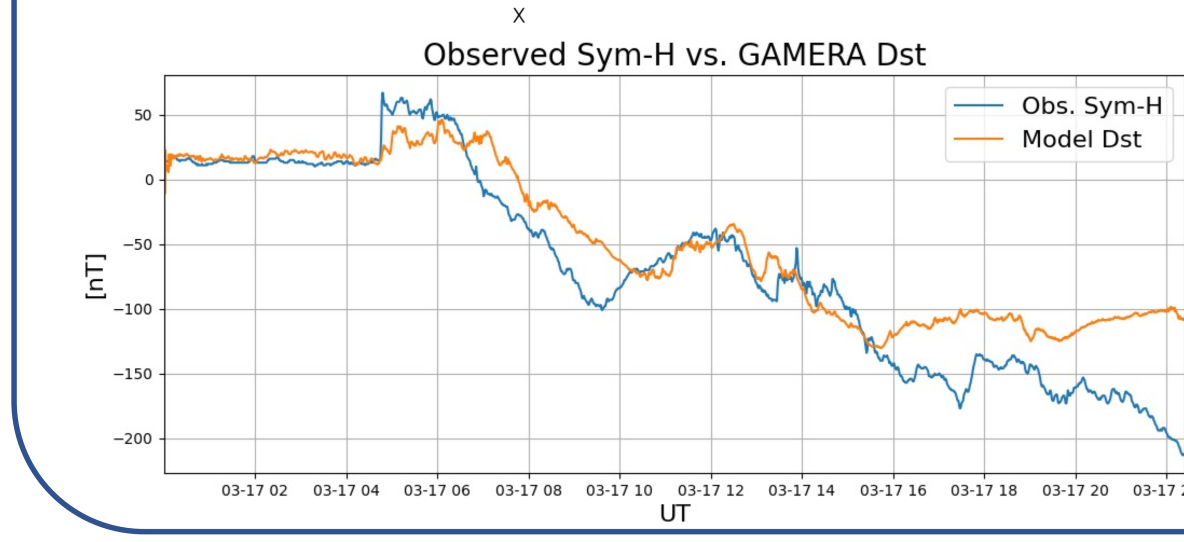
$$\frac{1}{\mu_0} \nabla \times \vec{B} = \vec{J}$$

Stephens et al. (2020), *Space Weather*, 10.1029/2020SW002583
Sitnov et al. (2017), 10.1002/9781119216346.ch15

Physics-Informed Empirical Pressure Ingestion Within the GAMERA Global MHD Model







Empirical model's pressure and flux tube volumes are provided to GAMERA on a grid in the ionosphere

Field-line tracing from ionosphere maps out GAMERA inner magnetosphere

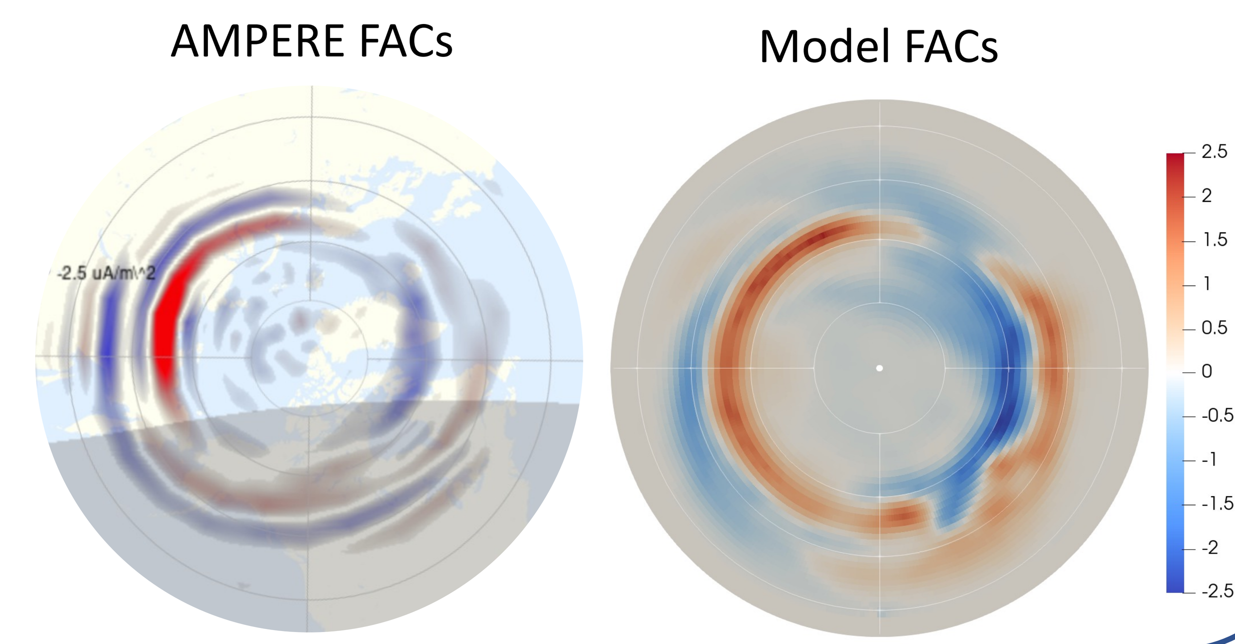
Target pressure is determined by equating flux tube entropy between the empirical and MHD model per flux tube:

$$p_{target} = p_{emp} \left(\frac{V_{emp}}{V_{GAM}} \right)^{5/3}$$

Inclusion of flux tube volume scaling communicates differences between the two magnetic field topologies
This method is also much more stable than ingesting p_{emp} directly

GAMERA adjusts its pressure in the inner magnetosphere region towards p_{target} over timescale of 10's of seconds

p_{target} is recalculated every 15 seconds



Conclusions and Future Work

- Ingestion of empirical inner magnetosphere pressure into the MHD model produces realistic ionospheric currents and Dst profile
- Coupling with MHD model adds dynamic behavior (e.g. night-side injections, dynamic magnetopause boundary) to an otherwise static empirical pressure model

Advantages:

- Inner magnetosphere solution does not depend on MHD as a plasma source
  - Lower resolution MHD domain can still contain realistic inner mag. pressure
    - Also means faster run-time
  - Less sensitive to coupling parameters such as time cadence, etc.
- No initial conditions needed and faster "spin-up" compared to what is required by physics-based inner mag. models

Future Work:

- Use empirical pressure to constrain total pressure within a physics-based model (Rice Convection Model)
- Explore methods to allow interchange instabilities to resolve in a physical manner
- Boundary conditions for empirical field fitting informed by MHD