Magnetic Field Models for Geospace Particle Tracing

AMPS Interface Documentation

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1 Total field representation

AMPS typically represents the magnetic field as

$$\mathbf{B}(\mathbf{r}, t) = \mathbf{B}_{\text{int}}(\mathbf{r}, t) + \mathbf{B}_{\text{ext}}(\mathbf{r}, t), \tag{1}$$

where $\mathbf{B}_{\text{int}}$ is the internal (main) field and $\mathbf{B}_{\text{ext}}$ is the magnetospheric current system contribution.

2 Internal field (IGRF / dipole)

For most applications, $\mathbf{B}_{\text{int}}$ is modeled using IGRF (or a dipole approximation for sensitivity testing). The internal field provides the dominant contribution near Earth and controls low-altitude cutoffs.

3 Empirical external field models (Tsyganenko family)

Empirical models represent $\mathbf{B}_{\text{ext}}$ using parametrizations constrained by spacecraft observations. Typical inputs are solar-wind dynamic pressure, IMF B_y/B_z, Dst, and/or Kp.

T96

Tsyganenko (1996) provides a widely used external field model suitable for many cutoff studies.

TS05 (Tsyganenko & Sitnov 2005) / TA15 (Tsyganenko–Andreeva 2015)

Storm-time models incorporate additional drivers and are designed to capture disturbed intervals. For SEP cutoff calculations, these models are often preferred for event-realistic reconstructions and strong-storm sensitivity tests.

Driver sets. In this interface, the "TS05" model is configured with the common scalar drivers (Dst or SYM-H, solar-wind dynamic pressure P_{dyn}, IMF $B_x/B_y/B_z$, solar-wind V_x and density N) and an `EPOCH` time tag. The underlying TS05 formulation is *dynamical*: the magnitudes of major current systems are driven by six history-dependent variables $W_1..W_6$, each computed as a relaxation integral/sum over the prior solar-wind/IMF conditions. Tsyganenko & Sitnov (2005) define (their Eq. (7–8)) a generic form

$$W(t_i) = \frac{r}{12} \sum_{k=1}^{i} S_k \exp\left[\frac{r}{60}(t_k - t_i)\right], \qquad S_k = \left(\frac{N_k}{5}\right)^{\ell} \left(\frac{V_k}{400}\right)^{b} \left(\frac{B_{s,k}}{5}\right)^{g}, \tag{2}$$

with module-specific exponents and relaxation rates. This is why TS05 is best driven from an OMNI-style time series (5-min cadence).

OMNI/TS05 record format. A commonly used dataset is distributed as yearly files `YYYY_OMNI_5m_with_TS05_v` where each 5-min record contains IMF (B_x, B_y, B_z), solar-wind velocity components, density, temperature, `SYM-H`, availability flags, dipole tilt angle (radians), P_{dyn} (nPa), and the six TS05 driving variables $W_1..W_6$.

Parameter presets (order-of-magnitude). Quiet solar wind typically corresponds to $P_{dyn} \sim$ 1–3 nPa, $|B_z| \lesssim 5$ nT, $V_x \sim -400$ km/s, $N \sim 3$–10 cm^{-3}; storm main-phase intervals commonly reach $P_{dyn} \sim 5$–15 nPa, $B_z \sim -10$ to -30 nT, $V_x \sim -600$ to -800 km/s, and Dst/SYM-H $\lesssim -100$ nT.

4   MHD-driven fields (BATSRUS / GAMERA)

For highest fidelity, AMPS can ingest a 3D time-dependent magnetic field from a global MHD model. In this mode:
- The MHD solution provides $\mathbf{B}(\mathbf{r}, t)$ (and optionally $\mathbf{E}$).
- Particle tracing uses spatio-temporal interpolation on the MHD grid.
- Boundary surfaces (magnetopause, inner boundary) should be consistent with the MHD domain.

This option is computationally heavier but can reproduce event-specific structures not captured by analytic fits.

5   Notes for cutoff calculations

- Using a storm-time external model (e.g., TS05/T15) can change R_C by several GV at mid-latitudes.
- Time dependence can be critical during rapid Dst changes; ensure Δt in tracing resolves the driver cadence.
- Consistency with the electric field model matters for drift trajectories, especially in the inner magnetosphere.

6   References (selected)

- Tsyganenko, N. A. (1996). "Effects of the solar wind conditions on the global magnetosphere configuration..." *JGR.*
- Tsyganenko, N. A., & Sitnov, M. I. (2005). (TS05). *JGR.*
- Tsyganenko, N. A., & Andreeva, V. A. (2015). (T15). *JGR.*