Modeling the Space Environment

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Why Model?

Models are an attempt to recreate complicated physical systems.

- Model performance tells us how well we understand a system.
- Give insight to how system works
- Models can reveal interactions and processes that were previously unknown.
- Model results are not limited by instrument coverage
Model Development

- A “perfect” model would contain all possible physical mechanisms.
- This is unrealistic!
  - The model would take forever to finish using even the most powerful computer.
  - We don’t know all the physics yet!
- Models start with only the most important physical processes.
- Model complexity is limited by computing power.
• The space environment is composed of many different interacting domains.
• The important physical processes change from domain to domain.
MHD Models

- **MagnetoHydroDynamics** combines gas dynamic equations with the Maxwell equations.
- Typically treats plasma as a single-species, collisionless fluid.
- Solves for density, momentum, magnetic field and total energy.

\[
\begin{align*}
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) &= 0 \\
\rho \frac{\partial \vec{u}}{\partial t} + \rho \vec{u} \cdot \nabla \vec{u} + \nabla p - \vec{j} \times \vec{B} &= 0 \\
\frac{\partial p}{\partial t} + \vec{u} \cdot \nabla p + \gamma p \nabla \cdot \vec{u} &= 0 \\
\frac{\partial \vec{B}}{\partial t} + \nabla \times \vec{E} &= 0 \\
\vec{j} &= \frac{1}{\mu_0} \nabla \times \vec{B} \\
\vec{E} &= -\vec{u} \times \vec{B}
\end{align*}
\]
MHD Models

Strengths:
- Works on large scale domains
- Speedy!
- Captures large scale magnetospheric fluctuations well
- Does a good job on magnetic field

Weaknesses:
- Small scale particle interaction effects are not captured well
- Reconnection occurs due to artificial sources
- Single fluid is bad.
Popular MHD Models:

- Lyon-Fedder-Mobarry (LFM)
- Open Geospace General Circulation Model (OpenGGCM)
- Block Adaptive Tree Solar-wind Roe-type Upwind Scheme (BATS-R-US)
- Robert Winglee’s Model
Inner Magnetosphere Models investigate the ring current, plasma sheet, plasmasphere, and radiation belt.

- All use bounce-averaged kinetic drift physics to model the closed field line inner magnetosphere region.

Examples:
- Rice Convection Model (RCM)
- Ring current Atmosphere interaction Model (RAM)
Particle Models

- Tracks individual particles in system
- Uses Lagrangian and Eulerian formulations of mechanics.
- Two flavors: Test particle and PIC
- Captures small details of system very well!
- Computationally expensive!
Data Driven Methods

Assimilative Models - Uses data to improve your solution.

Empirical Models - Uses trends in data to create a function to predict a system’s response to a given driver.
Expanding Model Capabilities

• By adding more physics, codes become more capable (but potentially much slower!)
  – Example: Multi-fluid MHD
  – Example: Hall MHD
• Hybrid models
• Alternatively, you can “couple” two codes together.
Coupling

- Each model independently creates a solution for its own domain.
- Periodically, the domains are “coupled”: solutions from one model is used to adjust the solution of another.
- The strengths of one model is shared with the others, creating a more accurate solution.

Hey, your B-field sucks. Use mine.

Thanks. Here’s a realistic thermal pressure for you.
Wrap-Up

- Modeling is especially important in the magnetosphere where data is sparse!
- The near-Earth environment requires many modeling methods to accurately recreate!
- The end goal is to create a Global Geospace Circulation Model!