Modeling the Near-Earth Space Environment with the SWMF

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SWMF
Center for Space Environment Modeling
Space Weather Modeling Framework
Near-Earth Models of the SWMF

- Community-based Whole Magnetosphere Model
- Funded by NSF, DoD, and NASA through LWS project
- Goal is to make the most physically self-consistent model of the near-Earth space environment.
- Current status shown
Coupling Example – 1
Improved Ionospheric Electrodynamics

Old – CPCP ~315 kV
New – CPCP ~606 kV

Take diffuse aurora and region-2 currents from RCM.
Coupling Example – 2
Oxygen and Hydrogen to Ring Current

- Multifluid code coupled to RCM
- Can drive GM with realistic outflows (O+ and H+) through PW
- Then drive RCM with realistic constituent densities
Code Improvements - Multifluid MHD

- Multifluid Code
  - Can have any number of separate species (typically run with H+ & O+)
  - Each has own continuity, momentum and energy equation
  - Coupled through viscosity/collision/friction terms
  - Can be coupled through chemistry, but not so important in the magnetosphere.
Code Improvements – 2
Spherical Magnetosphere

• We have implemented a spherical grid in BATSRUS
• Should help with diffusion in the inner magnetosphere
• Have tried out many different resolutions and configurations
• Mostly works with RCM coupling, but field-line tracing is still an issue
• Haven’t quantified improvement, since field-line tracing not perfected
Code Improvements – 3
Improved Ionospheric Electrodynamics

- New Ionospheric Potential Solver
- Fully parallel – latitude slices
- Forces potential to be the same between Northern and Southern hemisphere on closed field line, while polar caps are free.

Start

Fini
Global Ionosphere Thermosphere Model

GITM solves for:
- 6 Neutral & 5 Ion Species
- Neutral winds
- Ion and Electron Velocities
- Neutral, Ion and Electron Temperatures

GITM Features:
- Solves in Alt. coordinates
- Can have non-hydrostatic solution
  - Coriolis
  - Vertical Ion Drag
  - Non-constant Gravity
  - Massive heating in auroral zone
- Runs in 1D and 3D
- Vertical winds for each major species with friction coefficients
- Non-steady state explicit chemistry
- Flexible grid resolution - fully parallel
- Variety of high-latitude and Solar EUV drivers
- Fly satellites through model

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Validation of GITM

- Validation of GITM
- Ran GITM for entire year to compare to incoherent scatter radar measurements – here is a summer month

F10.7 Driven

FISM Driven
Upper Atmospheric Response to Flares

- Investigate the thermospheric and ionospheric reaction to a solar flare.
- October 28th flare is a very nice one to study.
The ionospheric response is more dramatic, since the density can change by orders of magnitude easily...
• The neutral winds that are responding to the thermospheric density change push the ionospheric density up and down the field-lines at mid-latitudes.
Uncertainty Estimation

• There are a large number of parameters in global ionosphere thermosphere models (knobs).
• These parameters have some range of (published) values (tunable knobs).
• The question is – How much difference does it make if you use one value over another value? This is the heart of Uncertainty Estimation.
• We chose a few parameters (thermal conductivity, Eddy diffusion coefficient, rates associated with NO, etc.) and investigated their effect on the thermosphere and ionosphere.
• In some ways, effects are obvious, but much larger than we expected.
Steady State

- The thermal conductivity has the largest effect on the temperature structure of any parameter
  - About 450 K globally averaged difference between one conductivity value and another!
- NO cooling is also extremely important, but is more constrained (even though there are more parameters)
- We didn’t even cover uncertainty in the INPUTS (solar EUV and high latitude forcing)
Storm-time

- We can then compare the effects of the different parameters on the neutral density at the Champ satellite.

- Using this type of information, we can forward propagate satellite orbits, with a growing cone of uncertainty.
  - Have nominal orbit as well as 25%, 50% and 75% uncertainty tracks.
The ionosphere is not as affected by these parameters as the thermosphere.

The Eddy diffusion ends up being the most important, since the O/N₂ ratio is strongly affected by this.

On a global scale, it isn’t much, but on the day side, there is a significant shift to lower densities (with larger Eddy diffusion coefficients).
Summary

• The Space Weather Modeling Framework extends from the low corona to the upper atmosphere of the Earth

• Working on improving the coupling in the near-Earth space environment by including more models and more complete coupling

• We have also been working on understanding the thermosphere and ionosphere
  – Solar flares have been a focus
  – Uncertainty Quantification will help us to put “error-bars” on our model results
    • Although system is so non-linear, ensembles need to be run
Questions?