CORHEL at the CCMC

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Introduction

• The ambient solar corona and solar wind play a key role in how the Sun influences the Earth’s space environment
• The region is vast in both real and parameter space
• Present/future missions sample the corona & inner heliosphere
• Coronal/solar wind models are required to synthesize these measurements into a coherent picture
• Important aspects of the physics of the corona and solar wind are still unknown or highly controversial.
• Models in different approximations are required for studying different aspects of solar and heliospheric physics.
What is CORHEL?

- CORHEL - “Corona-Heliosphere”
- A coupled set of models and tools for quantitatively modeling the ambient solar corona and solar wind
- The principal observational input to CORHEL are maps of the radial magnetic field at the photosphere, derived from solar magnetograms
- CORHEL provides coronal solutions using 3 approximations:
  - WSA model (numerical potential solver)
  - Polytropic MHD (MAS Code)
  - Thermodynamic MHD (MAS code)
- CORHEL provides two different heliospheric codes: Enlil & MAS
- CORHEL outputs plasma and magnetic field quantities in 3D space
- It also outputs observable quantities for validation
- CORHEL has been delivered to AFRL, CCMC, and CISM
CORHEL Features

- Allows input from 7 different Solar magnetographs
- Processes synoptic maps into boundary data for calculations
- The map processor is web based and interactive:
  - Interactive display of the raw magnetogram and processed map
  - Interactive display of pole fitting and smoothing
- Can provide cone model CMEs
- CORHEL has PSI’s implementation of the WSA model (with help from N. Arge)
  - Numerical Potential Solver
  - Allows consistent processing between WSA and MAS input
  - Allows for meaningful comparisons between WSA and MHD models, and comparison of different magnetograms
- Codes run on parallel architectures using MPI
CORHEL: Present Status

Magnetic Maps: MDI, MWO, NSO/KP, NSO/GONG, NSO/SOLIS, WSQ, HMI

Smoothing, Flux balance, Pole Fitting

Coronal Model Choices:
- WSA
- MHD (MAS) (Polytropic)
- MHD (MAS) (Thermodynamic)

Vr, Br, open/closed
- Empirical prescription
- Coronal Solution
- Coronal Solution

Radiative Outputs (EUV, X-Rays)
- White Light
- Observational Validation (White Light, EUV, X-ray, coronal holes)

Heliospheric Model Choices:
- Cone Model CME
- Enlil
- MAS

Observational Validation (In Situ Measurements, STEREO Heliospheric Imaging)

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Tuesday, April 1, 14
MAS and CORHEL at the CCMC

- The MAS (Magnetohydrodynamic Algorithm outside a Sphere) code has been available at the CCMC for 11 years.
- The original MAS at CCMC was a serial code that provided MHD solutions for the solar corona, using Kitt Peak photospheric magnetic maps as boundary conditions.
- CCMC developed the original interface to MAS. CCMC supplied all of the manpower, with guidance from us.
- CORHEL is a far more complex product than the original MAS.
- As CORHEL has expanded in capability and sophistication, there are many more choices and uses not envisioned by the original interface.
A New Interface for CORHEL

- Users want more flexibility to tailor their runs.
- To access all of the features of CORHEL, users need an intuitive interface that guides them through different choices.
- We have also found that users like certain products derived from the solutions (e.g. coronal hole boundaries, pB, emission) that we provide on our web site.
- Interface development requires deep knowledge of CORHEL:
  - Requires many more man-hours for someone outside our team.
  - It is unrealistic to expect the CCMC to provide all of this manpower.
- We developed a new interface for CORHEL, and in close collaboration with CCMC staff, have ported it to the CCMC.
- Presented at interface at the 2012 workshop; the interface is now fully operational.
Thermodynamic MHD Model Now Available at CCMC

Corona Model: MAS Thermodynamic Parameters

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CORHEL at CCMC

1. Model Selections
   - Date and Model

2. Corona Boundary Conditions
   - Input Source
   - Input Parameters

3. Corona Model
   - MAS Thermodynamic Parameters
   - Heating Model Version I Parameters

4. Heliospheric Boundary Conditions
   - Input Source
   - Input Parameters

5. Heliospheric Model
   - ENLIL Parameters

6. Summary
   - Run Summary

Corona Model: MAS Thermodynamic Parameters

- Outer radius: 30.0 Rs
- Maximum time: 48 hours
- Lundquist number: 5.00e3
- Viscosity: 0.002
- Acceleration model: WKB
- Heating model: Heating Model Version I

Curator: Anna Chulaki | NASA Official: Dr. Michael Hesse | Privacy, Security Notices

CCMC logo designed by artist Nana Bagdadadze

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• To accurately simulate plasma density, a more sophisticated energy treatment is required (coronal heating, radiative cooling, thermal conduction)
  • $\gamma = 5/3$ retained for ratio of specific heats
• Can be validated by simulating emission in EUV and X-rays
Thermodynamic MHD Models

June 6 - July 3, 2010: Simulated and Observed Emission Lines

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Optimization of the MAS code

- In the solar corona, local regions can have very high Alfvén speed (e.g. active regions), making explicit calculations intractable.
- The semi-implicit solve in MAS allows the time step to greatly exceed the CFL condition (e.g. 100s of times CFL).
- We have spent a lot of effort in optimizing the MAS code:
  - Improved CG solvers for the implicit parts of our code.
  - Improved efficiency of matrix storage and matrix-vector multiplies.
  - Improved MPI communication.
- We have improved the preconditioning in the CG solve to use incomplete LU preconditioning, with variable fill-in, using an additive Schwarz decomposition.
- This reduces the number of iterations in our solvers, speeding up the code.
- As a result our newest version of the code can be up to 7 times faster!
- The optimized version will be implemented at CCMC soon.
 Optimization (continued)

- On parallel computers, communication is costly - one attempts to maximize computational work on a processor while minimizing communication between processors
- Thus, a solver that does a better preconditioning (i.e., more work) on the part of the matrix on each CPU, will reduce the number of iterations in the solve (i.e., less communication)
- Example:
  Zero-beta simulation of the energization of an active region, 151x237x312 mesh, on 720 processors, run on NASA Pleiades
- Semi-implicit solve (wall clock time):
  Old code, preconditioner with diagonal scaling: 38 sec/step, 495 iterations/step
  New code, ILU preconditioner w/additive Schwarz: 5 sec/step, 161 iterations/step
- The speedup is case-dependent, but there is a significant improvement in all cases
Incorporation of ADAPT Map Into CORHEL

- The Air Force Data Assimilative Photospheric Flux Transport (ADAPT) model (Arge et al. 2009) is based on Worden & Harvey (2000), which accounts for known flows in the solar photosphere:
  - Differential rotation
  - Meridional flow
  - Supergranular diffusion
  - Random flux emergence
  - Polar fields arise from long-term evolution
- ADAPT improves on the Worden&Harvey model by incorporating rigorous data assimilation methods into it.
- Present ADAPT maps are to be considered preliminary.
- Presently experimenting with the incorporation of far side images
Diachronic vs. Synchronic Maps (NSO SOLIS Magnetograms)

ADAPT:
July 11, 2010

SOLIS
CR2098
Diachronic vs. Synchronic Maps (NSO SOLIS Magnetograms)

Carrington Longitude

0 90 180 360

Co-latitude

0 90 180

ADAPT: July 11, 2010

SOLIS CR2098
Diachronic vs. Synchronic Maps: Coronal Hole Boundaries

Carrington Longitude

Co-latitude

Co-latitude

SOLIS CR2098

ADAPT:
July 11, 2010
Diachronic vs. Synchronic Maps: Coronal Hole Boundaries

ADAPT:
July 11, 2010

SOLIS
CR2098
Emission Comparison

AIA Observations
(2010/07/11 20:00:00)

ADAPT:
July 11, 2010

SOLIS CR2098
AIA Observations
(2010/07/11 20:00:00)

ADAPT:
July 11, 2010

SOLIS CR2098

AR present in emission, Coronal hole is thinner

Emission Comparison
Coupled MAS Coronal and Interplanetary Simulations: A CME Test

- Test simulation to 50 Rs (Polytropic MHD for simplicity)
- Left: Coupled simulations (coronal boundary at 20 Rs)
  Right: Entire domain is 50 Rs
- CME propagates seamlessly through the boundary
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Ongoing Work

- Time-dependent solar wind based on evolving photospheric $B_r$
  - Uses ADAPT model to evolve the flux
- Physics-based heating/acceleration models (wave-turbulence formalism)
- CME initiation and propagation in the corona
- Coupling with EPREM/EMMREM for SEP modeling
- Collaboration with Slava Merkin/John Lyon on LFM coupling