MHD Modeling for HMI:

Jon Linker

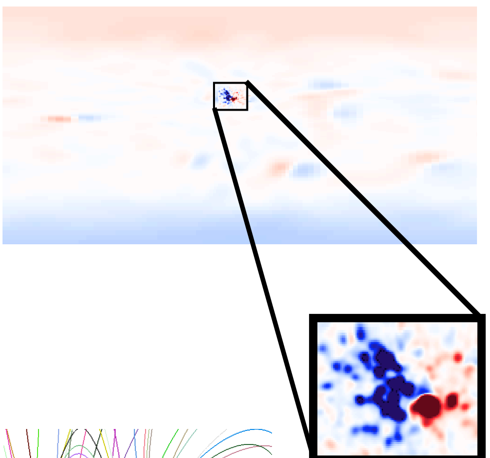
Zoran Mikic

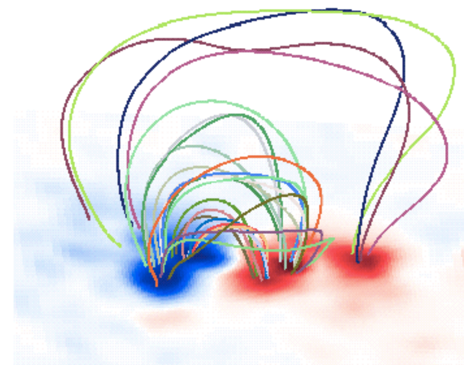
Science Applications Intl. Corp.

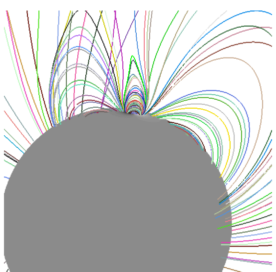
SAIC

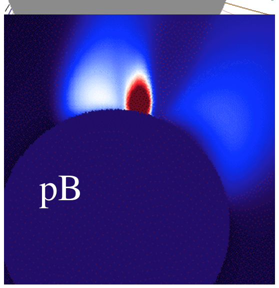
An Employee-Owned Company

San Diego, CA



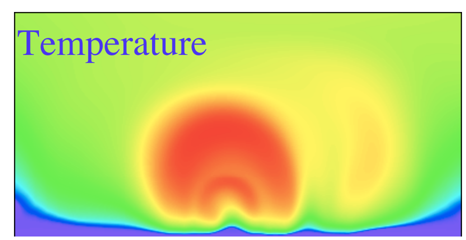






Presented at the HMI Team Meeting,

Stanford University, Palo Alto, January 26-27, 2005



My charter for Today

- Don’t focus on the great science you want to do
- What “data” products will SAIC provide through MHD modeling?
- Can/should the code be run locally at Stanford?
- If so, what computer resources will be required?
- What data inputs will the model need?
- Original Statement of work:
  - “SAIC will incorporate its 3D MHD solar wind model into the HMI analysis pipeline to produce high-level science data products.”

Today I’m assuming that this is still the goal.

My charter for Today

(blame Todd)

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Stated SDO Objectives

To understand the structure and evolution of the Sun's magnetic field on multiple length scales (magnetic elements, active regions, global corona, inner heliosphere) and time scales (solar cycle, active region evolution, bright points).

AIA and HMI will provide:

(1) Vector **B** in the photosphere on the solar disk.

(2) Strong constraints on the temperature/density structure of the lower solar atmosphere via emission measurements.

Models are necessary to synthesize these and other measurements into a coherent description of the corona and inner heliosphere.

SAIC Capabilities relevant to SDO

- Global modeling of the solar wind and CMEs
  - Solar wind structure [$\mathbf{v}(\mathbf{x},t)$, $n(\mathbf{x},t)$, $T(\mathbf{x},t)$, $\mathbf{B}(\mathbf{x},t)$] in the corona and inner heliosphere
    - $\mathbf{v}(t)$, $n(t)$, $T(t)$, $\mathbf{B}(t)$ at Earth and spacecraft positions
- Modeling of the *magnetic* structure of active regions
  - Using photospheric vector magnetic fields to determine coronal magnetic fields
  - Study of evolution and eruption mechanisms (e.g., shear, emergence/cancellation of magnetic flux)
- Modeling of the *thermal* structure of active regions
  - Density and temperature structure of active regions [$n(\mathbf{x})$ and $T(\mathbf{x})$ profiles], including the transition region
  - Prominence structure and topology
  - EUV and X-ray emission, and their relationship to coronal heating

MHD EQUATIONS
(POLYTROPIC MODEL)

$$\nabla \times \mathbf{B} = \frac{4\pi}{c}\mathbf{J}$$

$$\nabla \times \mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}$$

$$\mathbf{E} + \frac{1}{c}\mathbf{v} \times \mathbf{B} = \eta \mathbf{J}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = \frac{1}{c}\mathbf{J} \times \mathbf{B} - \nabla p + \rho \mathbf{g} + \nabla \cdot (\nu \rho \nabla \mathbf{v})$$

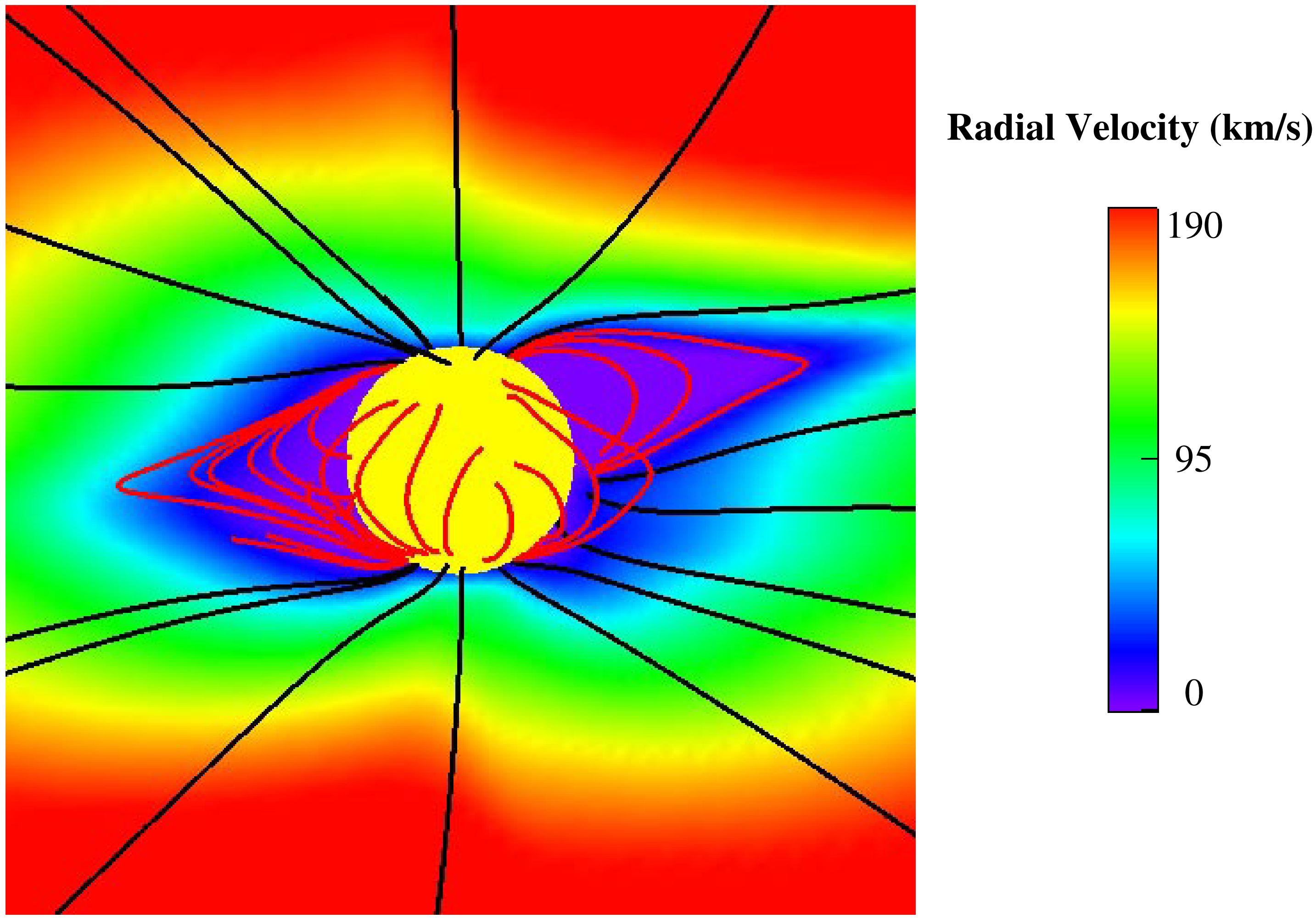
$$\frac{\partial p}{\partial t} + \nabla \cdot (p\mathbf{v}) = -(\gamma - 1)p\nabla \cdot \mathbf{v}$$

$\gamma = 1.05$ for coronal solution;
$\gamma = 1.5$ for heliospheric solution

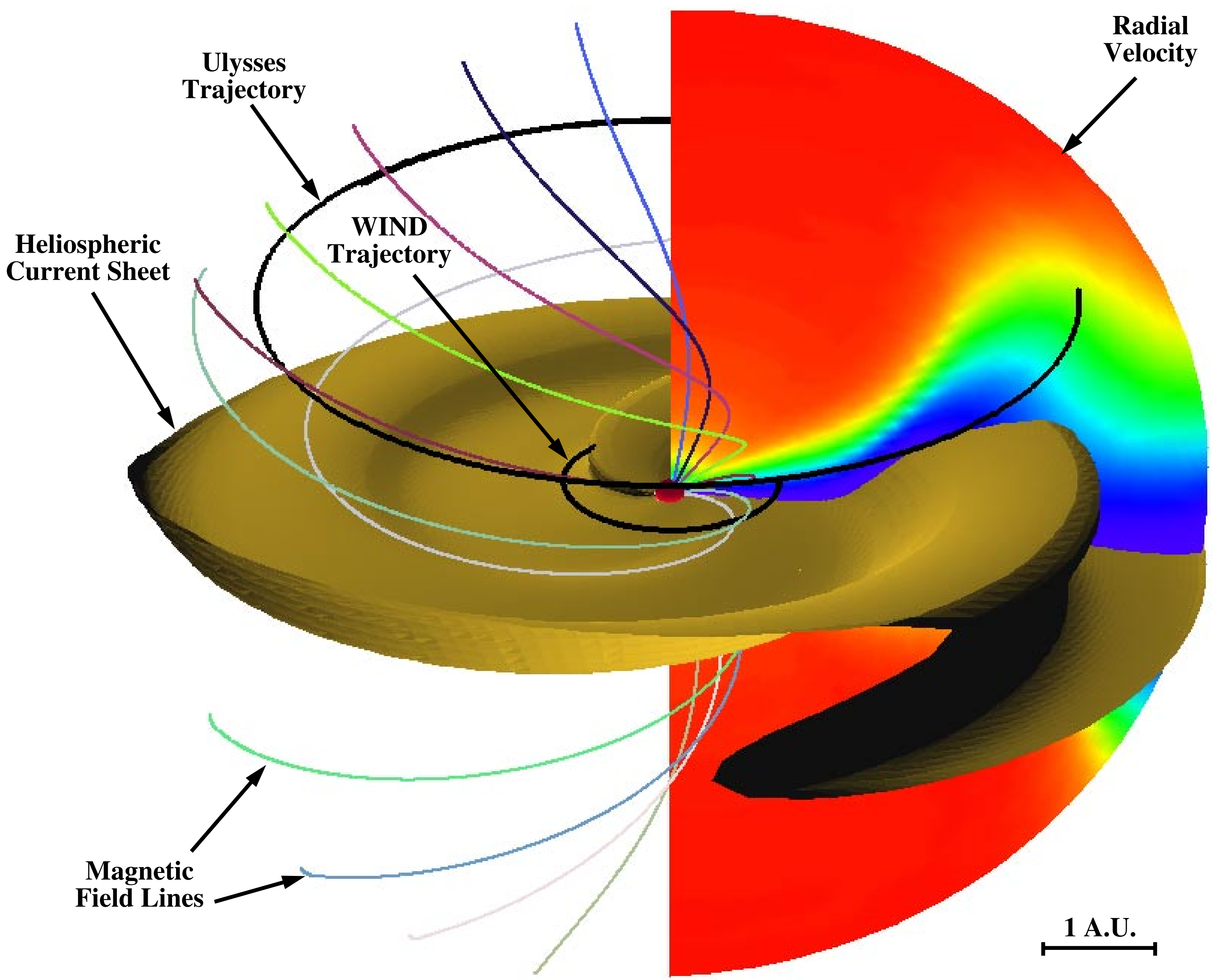
Whole Sun Month

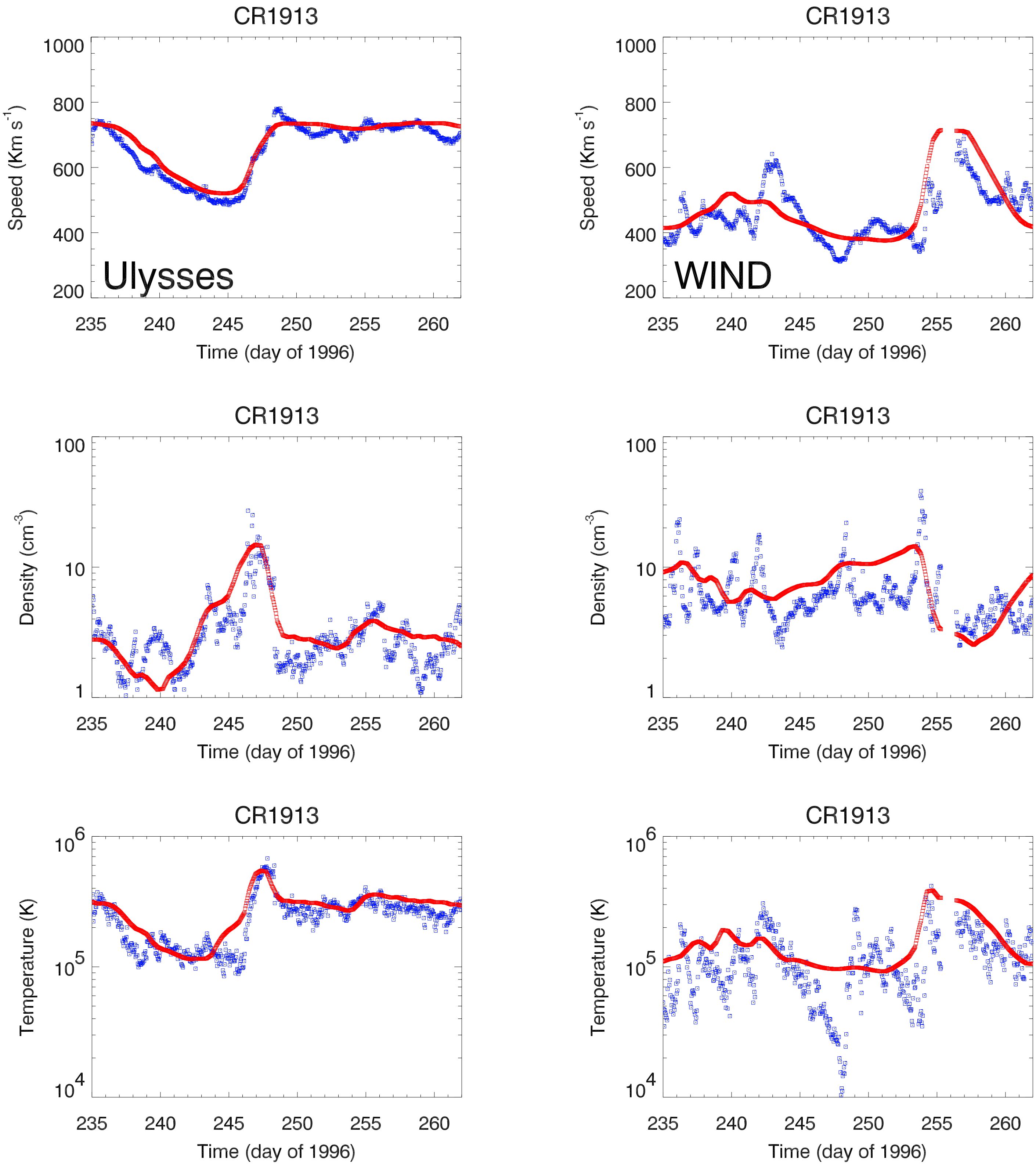
Aug. 10 – Sep. 8, 1996

Radial Velocity
Open and Closed Field Lines



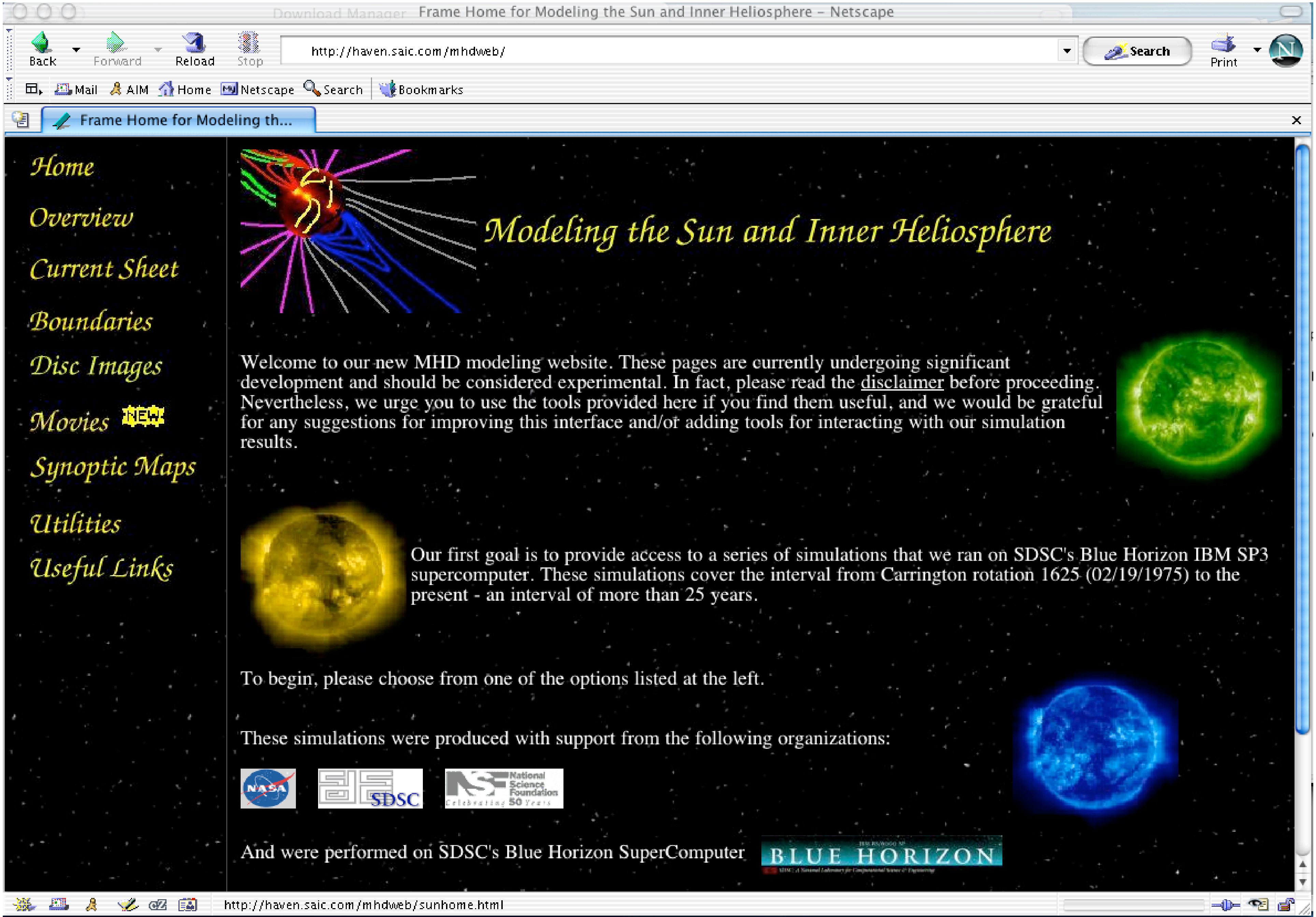
The Heliosphere During Whole Sun Month
August   September 1996





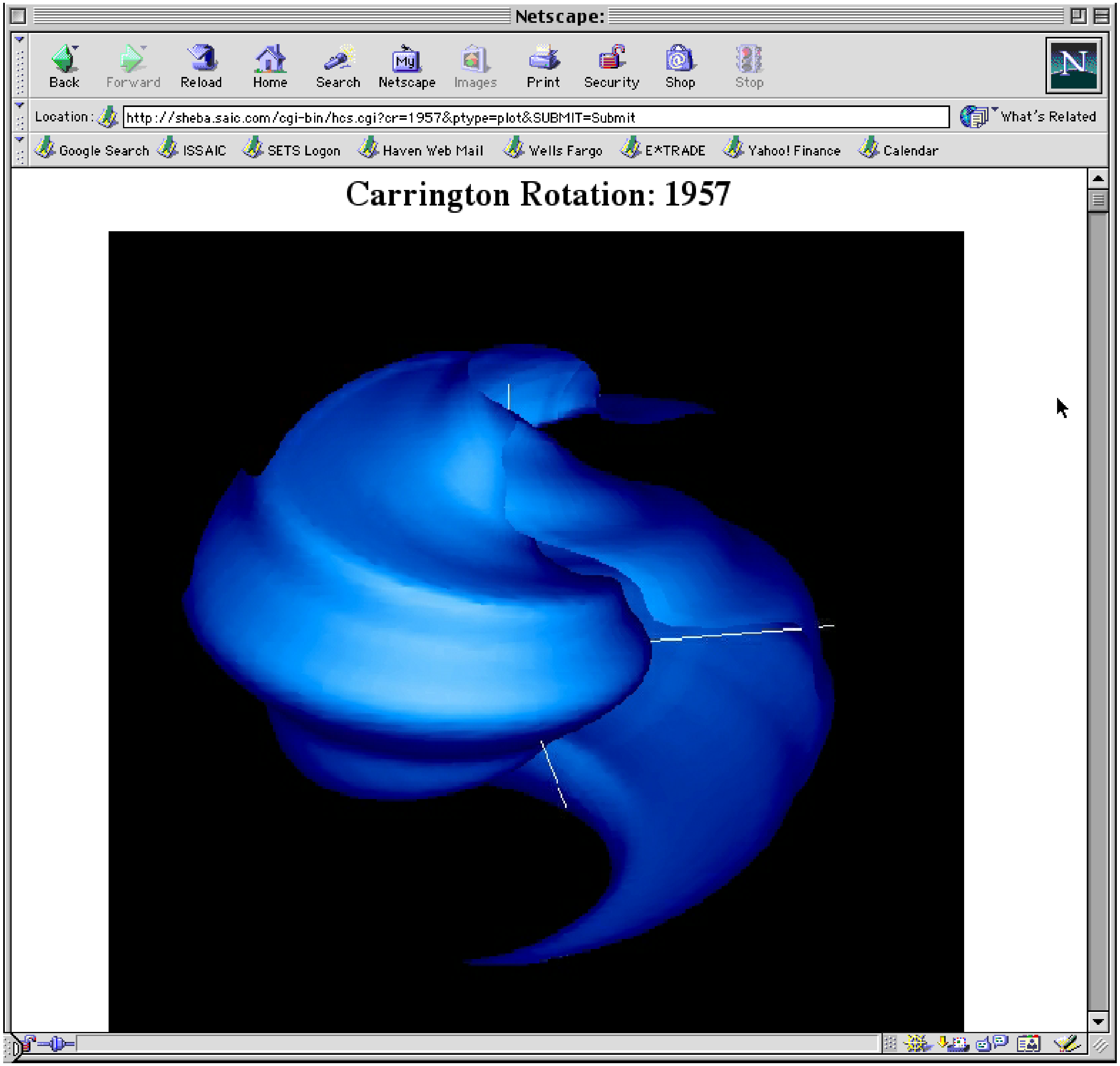
CR1913
Speed (Km s-1)
1000
800
600
400
200
Ulysses
235 240 245 250 255 260
Time (day of 1996)
CR1913
Speed (Km s-1)
WIND
Time (day of 1996)
CR1913
Density (cm-3)
100
10
1
Time (day of 1996)
CR1913
Density (cm-3)
Time (day of 1996)
CR1913
Temperature (K)
10^6
10^5
10^4
Time (day of 1996)
CR1913
Temperature (K)
Time (day of 1996)

Prototype Web Page



STANDARD DATA PRODUCTS

- We are developing WWW site with data for 2.5 solar cycles (~ 350 Carrington rotations, CR 1625 – present)
- Coronal hole maps with magnetic field polarity
- Field line connectivity (spacecraft to source regions on the Sun)
- Plasma parameters: $\mathbf{B}$, $\mathbf{v}$, T, n
    - plots vs. latitude, longitude, radius
    - meridional and equatorial cuts
- Limb *pB* images at Earth and spacecraft views, movies of *pB*
- Synoptic maps of *pB* at various radii
- 3D images of the heliospheric current sheet and field lines (VRML)
- Raw data: $\mathbf{B}(\mathbf{x},t)$, $\mathbf{v}(\mathbf{x},t)$, $T(\mathbf{x},t)$, $n(\mathbf{x},t)$
- Future products: Interactive tools (e.g., field line tracing on demand)


Netscape:
Back
Forward
Reload
Home
Search
Netscape
Images
Print
Security
Shop
Stop
Location: http://sheba.saic.com/cgi-bin/hcs.cgi?cr=1957&ptype=plot&SUBMIT=Submit
What's Related
Google Search
ISSAIC
SETS Logon
Haven Web Mail
Wells Fargo
E*TRADE
Yahoo! Finance
Calendar
Carrington Rotation: 1957

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Curator: Ms. Ayris Falasca

CCMC Space Weather Models

- The CCMC works with the research community on the creation of advanced-capability space research models, focusing on space weather applications.
- In support of space science research the CCMC provides, to the research community, the results of selected runs and all runs-on-request.
- The CCMC requests customer feedback on the scientific use and viability of model results made available here.
- If results from runs-on-request are used in a scientific publication or presentation the CCMC requests that, at a minimum, the authors acknowledge the CCMC and the originators of the computational model. All users should contact the code developers for the purpose of publication. You may wish to offer co-authorship, or model owners may request co-authorship at their discretion.

  In addition, for tracking purposes for our government sponsors, we ask that you notify the CCMC whenever you use CCMC results in a scientific publication or presentation

Solar Models

- **MAS** - developed by J. Linker, Z. Mikic, R. Lionello, and P. Riley
- **PFSS** - developed by J. Luhmann et al.

Heliosphere Models

- **IPS** - developed byB. Jackson and P. Hick
- **Exospheric Solar Wind Model** - developed by H. Lamy and V. Pierrard

Global Magnetosphere Models

- **BATS-R-US** - developed by the Center for Space Environment Modeling (University of Michigan)
- **UCLA-GGCM** - developed by Jimmy Raeder

Inner Magnetosphere Models

- **Fok Ring Current/Radiation Belt Model** - developed by Mei-Ching Fok

Ionosphere/Thermosphere Models

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Step 3: Set The Simulation Time Interval

Choose Carrington rotation or date at the beginning of the run

Select:

Carrington rotation number between 1625 and 2007: 2007

or

Date (MM/DD/YYYY) between 02/18/1975 and 08/29/2003 08 / 29 / 2003

Selection of Carrington rotation numbers and dates is subject to change.

Specify the duration of the run

40 hours

Maximum duration of the run is 80 hours of real time.
Minimum duration of the run is 5 hours of real time.

Step 4: Set The Simulation Grid

Select **grid resolution (NRxNTxNP)** from predefined list:

low-resolution (61x51x32)

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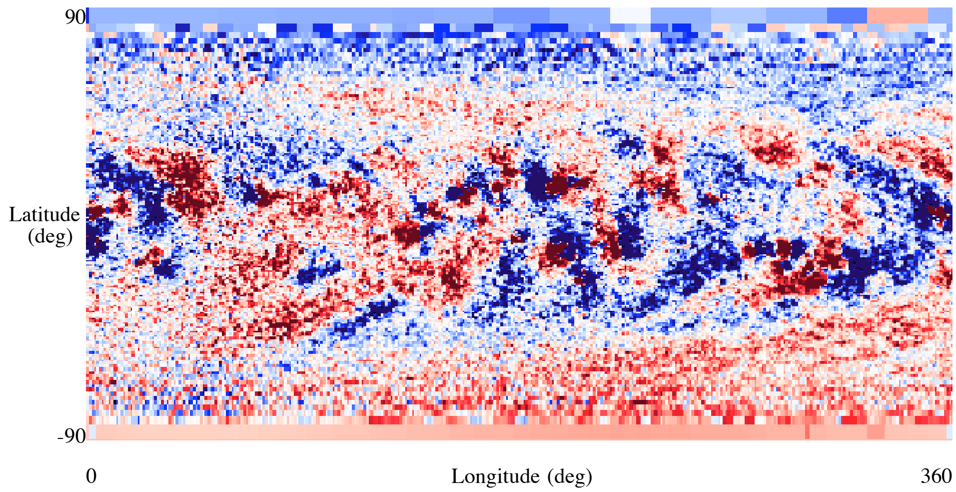
Curator: Ms. Ayris Falasca
NASA Official: Dr. Michael Hesse

Zoran_Mikic_090803_SH_1

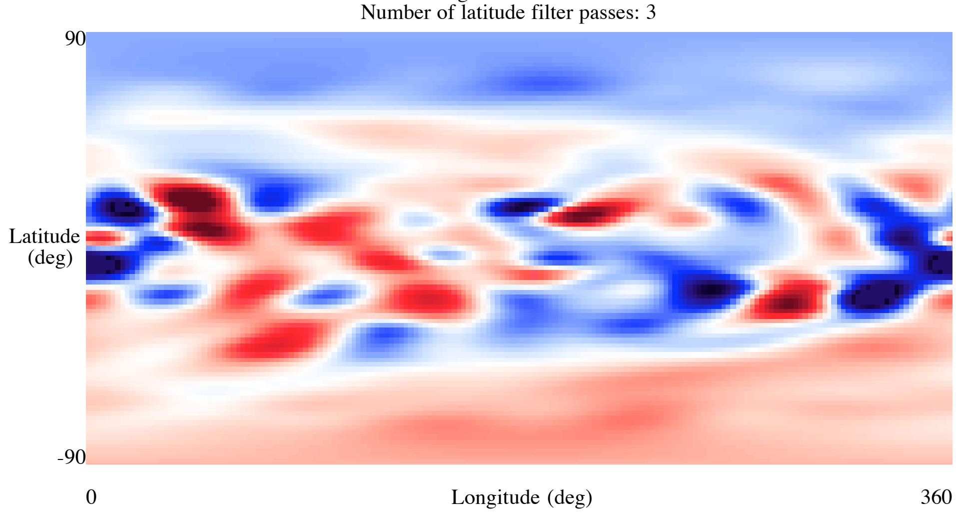
Carrington Rotation: 2005

Raw Kitt Peak Magnetogram

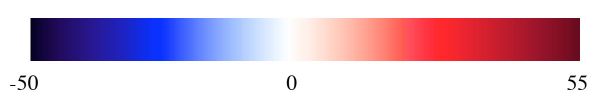


Filtered Kitt Peak Magnetogram

Filter Parameters:
Maximum longitudinal mode number: 6
Number of latitude filter passes: 3



Radial Magnetic Field Magnitude [Gauss]



Capabilities of MAS at CCMC

- The capabilities of the MAS model at CCMC have been deliberately curtailed
- A conservative approach has been used to minimize the chance of code failure; nevertheless, the code will probably still fail
- Intrinsically, this is a research code that is being made available to users in the belief that this may prove to be a useful exercise
- Capabilities of MAS at CCMC:
  - Polytropic MHD model
  - Driven by (filtered) Kitt Peak magnetic field maps
  - Choice of low (61 × 51 × 32) and medium (85 × 81 × 64) resolution meshes
  - Choice of base density and temperature in the corona
  - Relaxation to steady state
  - Increased viscosity and resistivity
  - Runs on a single CPU

New MAS code has a number of improvements:

- Written in Fortran 90
- Designed to run on massively parallel computers using MPI:
  - Linux and Beowulf Clusters (lf95, pgf90, Intel Fortran)
  - Mac (Absoft and xlf)
  - IBM SP3 and SP4
- Mesh decomposition among processors in 3D
- Dynamic allocation allows mesh size and number of processors to be allocated at run time
- Nonuniform mesh in ϕ as well as r and θ

Likely Physics Improvements to MAS (Non-HMI specific)

- Experience gained from modeling active region fields within the global corona
- Experience gained from modeling CME events from real active regions
- Studies of CME initiation mechanisms (mainly flux cancellation and breakout)
- More routine calculation using full thermodynamic model
- Attempts at coronal computation using full-disk vector magnetic maps (SOLIS)

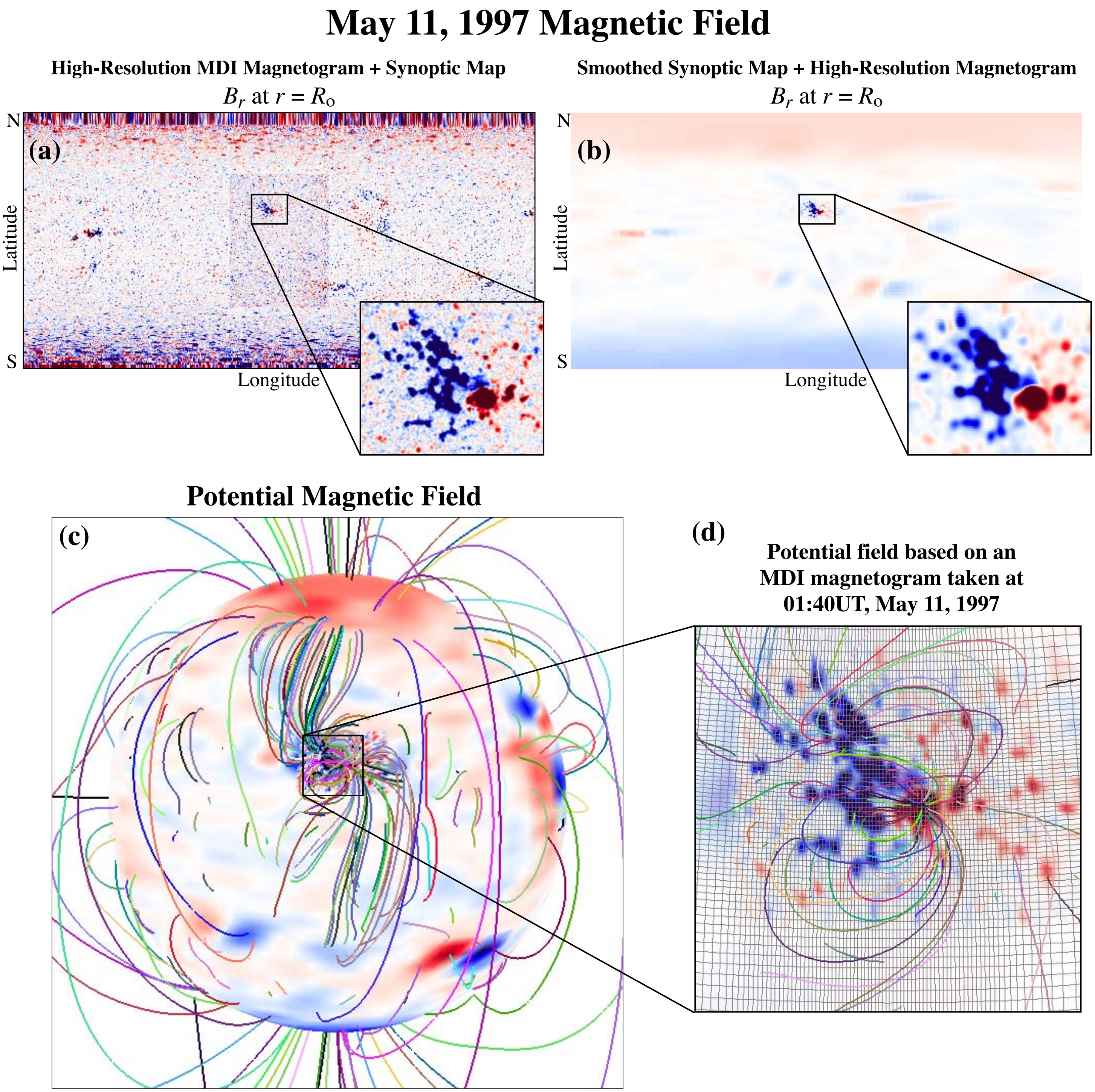


Fig. 3. The potential magnetic field on May 11, 1997 determined from MDI magnetograms and synoptic maps. (a) A high-resolution MDI magnetogram taken at 01:40UT on May 11 embedded into a high-resolution MDI synoptic map. (b) A smoothed version of the magnetic field with high resolution in the active region and smoothed fields outside the active region that is approprate for driving MHD simulations. (c) Magnetic field lines in the potential field that mathces the photospheric field in (b). (d) A zoom of the field ines in the active region, showing the computational mesh.

AN EVOLVING SOLAR WIND MODEL

- We can run a time-dependent coronal model with continuous updates of the photospheric magnetic field driven by observations
- We can use daily or more frequent updates (determined primarily by resources)
- The boundary magnetic field B_{r_0} in the model is updated using an electric field at the boundary
- The coronal solution and solar wind respond to the boundary condition changes
- A "quasi-real-time" model can be developed if a massively parallel computer is used (e.g., a Beowulf cluster with 32 processors) for a medium-resolution run [$\sim O(100^3)$ mesh points]

Improvements necessary for HMI-driven Solutions

- "Automatic" localized high resolution in selected active regions
- Solutions updated more frequently
- Routine solutions of large-scale corona with vector magnetograms
- Ultimate approach is a "quasi-real" time model:
  - Time-dependent solutions that incorporate sequences of magnetograms
  - Examples already performed with line-of-sight magnetic maps
  - Extend "evolutionary technique" to vector fields
- Linking with Karel Schrijver's flux evolution calculations fits naturally into this goal

Can "real-time" MAS be run at Stanford?

- Yes, but:
  - MHD modeling for the non-expert is in its infancy (e.g. CCMC)
  - This is a research code. Adapting the code to a production environment is non-trivial.
  - Requires significant work in making the code ready for production and working with Stanford staff to transition the code to the processing environment
- This may be a more cost-efficient approach in the long run than SAIC running and providing data.
- For $\sim 10^6$ grid points run in real time, will need ~32 processor Beowulf in 2008 (128 procs today).

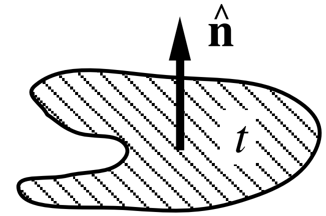
Data Inputs to the Model

- Line-of-sight or vector magnetic field, as a full Sun map
- For vector field, require well-processed data, ambiguity resolution.
- Can use highest resolution data (e.g. have already used 2 arc sec MDI) but only in selected regions
- We will need to work with Stanford to develop a processing protocol for magnetic maps destined for the MHD calculation
- Cadence? A few good magnetograms are better than a lot of bad ones

Summary

- The incorporation of routine MHD modeling as a part of HMI data processing will represent a significant advance in community science analysis products
- A "quasi-real-time" model will provide the most frequent cadence of solutions
- It is an ambitious goal, but achievable

USING A SEQUENCE OF VECTOR MAGNETOGRAMS



- Boundary tangential electric field (definition):

$$\mathbf{E}_t = \nabla_t \times (\Psi \hat{\mathbf{n}}) - \nabla_t \Phi$$

- Evolution of the normal boundary magnetic field, B_n:

$$\frac{1}{c}\frac{\partial B_n}{\partial t} = -\hat{\mathbf{n}}\cdot\nabla_t \times \mathbf{E}_t = \nabla_t^2 \Psi$$

⇒ A sequence of magnetograms can be used to determine Ψ

- Evolution of the normal boundary current density, J_n:

$$\frac{\partial \Phi}{\partial t} = \frac{\eta\, l}{\tau_{RC}}(J_n^{\text{o}} - J_n)$$

where: l is the scale length of the active region (input)

τ_{RC} is the R–C time for the capacitor controlling the current source J_n^{o} (input)

$J_n^{\text{o}} = \frac{c}{4\pi}\hat{\mathbf{n}}\cdot\nabla_t \times \mathbf{B}_t$ is deduced from a sequence of vector magnetograms

USING VECTOR MAGNETOGRAMS: THEORY

- Force-free approximation: assume that the coronal plasma pressure is small ($\nabla p = 0$). The coronal plasma is thus force-free:

$$\frac{c}{4\pi}\nabla \times \mathbf{B} = \alpha \mathbf{B}$$

- Topological constraint: $\mathbf{B}\cdot\nabla\alpha = 0$
- Force-free fields (FFF): some theory exists (but it is a nonlinear problem)
- A stable technique requires a boundary-value formulation with boundary conditions on B_n and J_n (Schmidt 1968; Bineau 1972)
- Constant α theory has been used (limited usefulness)
- Nonlinear FFF (α non-constant):
  - Iterative techniques based on Grad–Rubin (1958): Sakurai (1981), Amari *et al*. 1996
  - Minimization technique: Roumeliotis (1994)
  - Extrapolation in height: Wu *et al*. (1990): limited height—unstable
  - Evolutionary technique: FFF is the asymptotic state of a resistive time-dependent problem (Mikić, McClymont, *et al*. 1994)

Improved Energy Transport Model

- The Polytropic Model *qualitatively* reproduces many aspects of coronal structure
- It is not *quantitatively* accurate:
  - The density contrast between streamers and coronal holes and is ~ 2 (observed ~5-10)
  - There is no fast wind; contrast between "fast" and slow wind is ~20% (observed ~2)
- Energy transport processes play a key role in the transition region and lower corona:
  - Anisotropic thermal conduction, radiative losses, coronal heating
  - 1D models that include these processes have existed for years: Challenging to include in 2D & 3D
  - Momentum source apparently necessary to reproduce fast wind properties

MHD Equations
(Improved Energy Equation Model)

$$\nabla \times \mathbf{B} = \frac{4\pi}{c} \mathbf{J}$$

$$\nabla \times \mathbf{E} = -\frac{1}{c} \frac{\partial \mathbf{B}}{\partial t}$$

$$\mathbf{E} + \frac{1}{c} \mathbf{v} \times \mathbf{B} = \eta \mathbf{J}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

$$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = \frac{1}{c} \mathbf{J} \times \mathbf{B} - \nabla p - \nabla p_w + \rho \mathbf{g} + \nabla \cdot (\nu \rho \nabla \mathbf{v})$$

$$\frac{\partial p}{\partial t} + \nabla \cdot (p \mathbf{v}) = (\gamma - 1) \left(-p \nabla \cdot \mathbf{v} - \nabla \cdot \mathbf{q} - n_e n_p Q(T) + H \right)$$

$$\gamma = 5/3$$

$$\mathbf{q} = -\kappa_{\parallel} \hat{\mathbf{b}} \hat{\mathbf{b}} \cdot \nabla T$$ (Close to the Sun, $r \lesssim 10 R_S$)

$$\mathbf{q} = 2 \alpha n_e T \hat{\mathbf{b}} \hat{\mathbf{b}} \cdot \mathbf{v} / (\gamma - 1)$$ (Far from the Sun, $r \gtrsim 10 R_S$)

+ WKB equations for Alfvén wave pressure p_w evolution

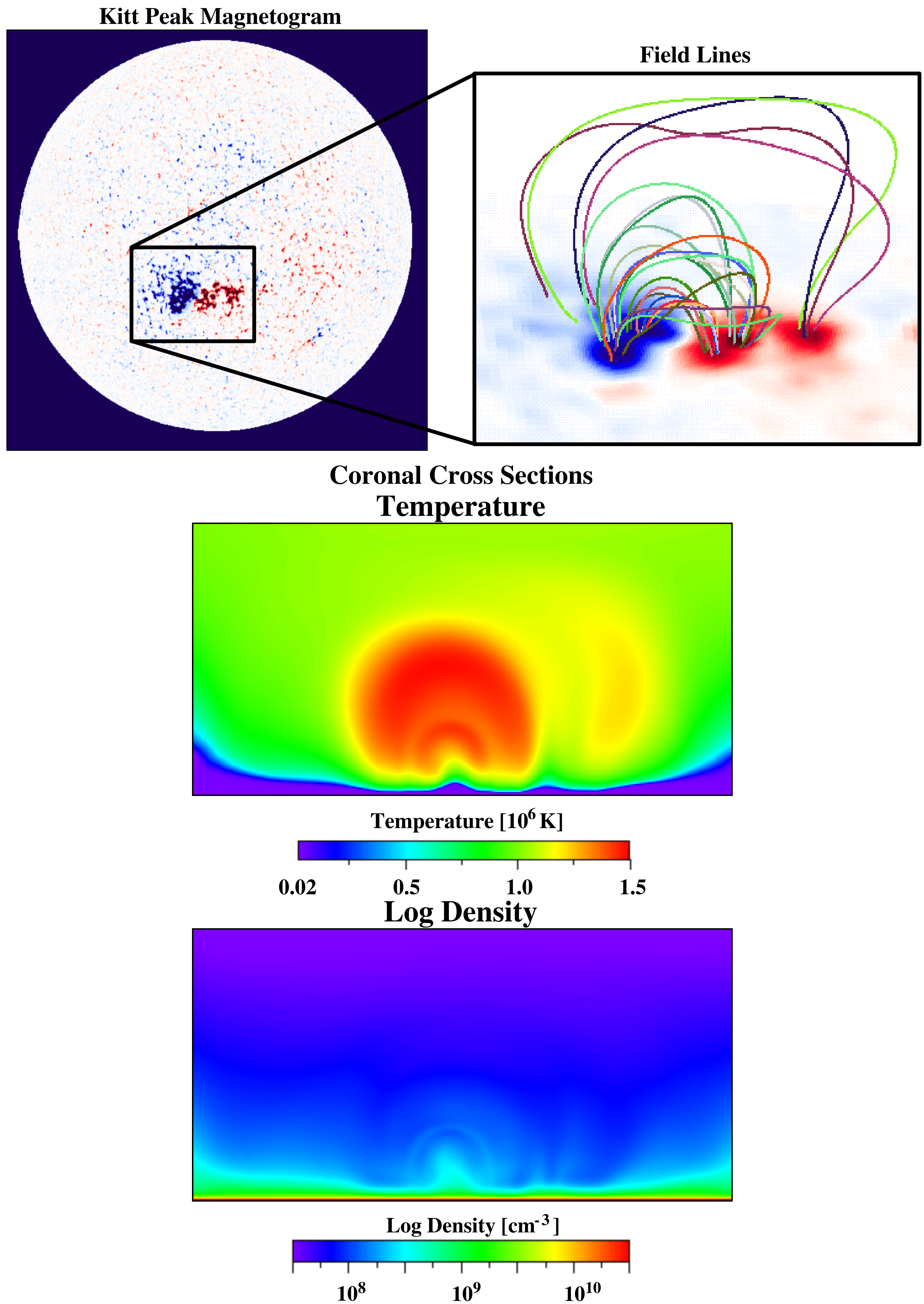
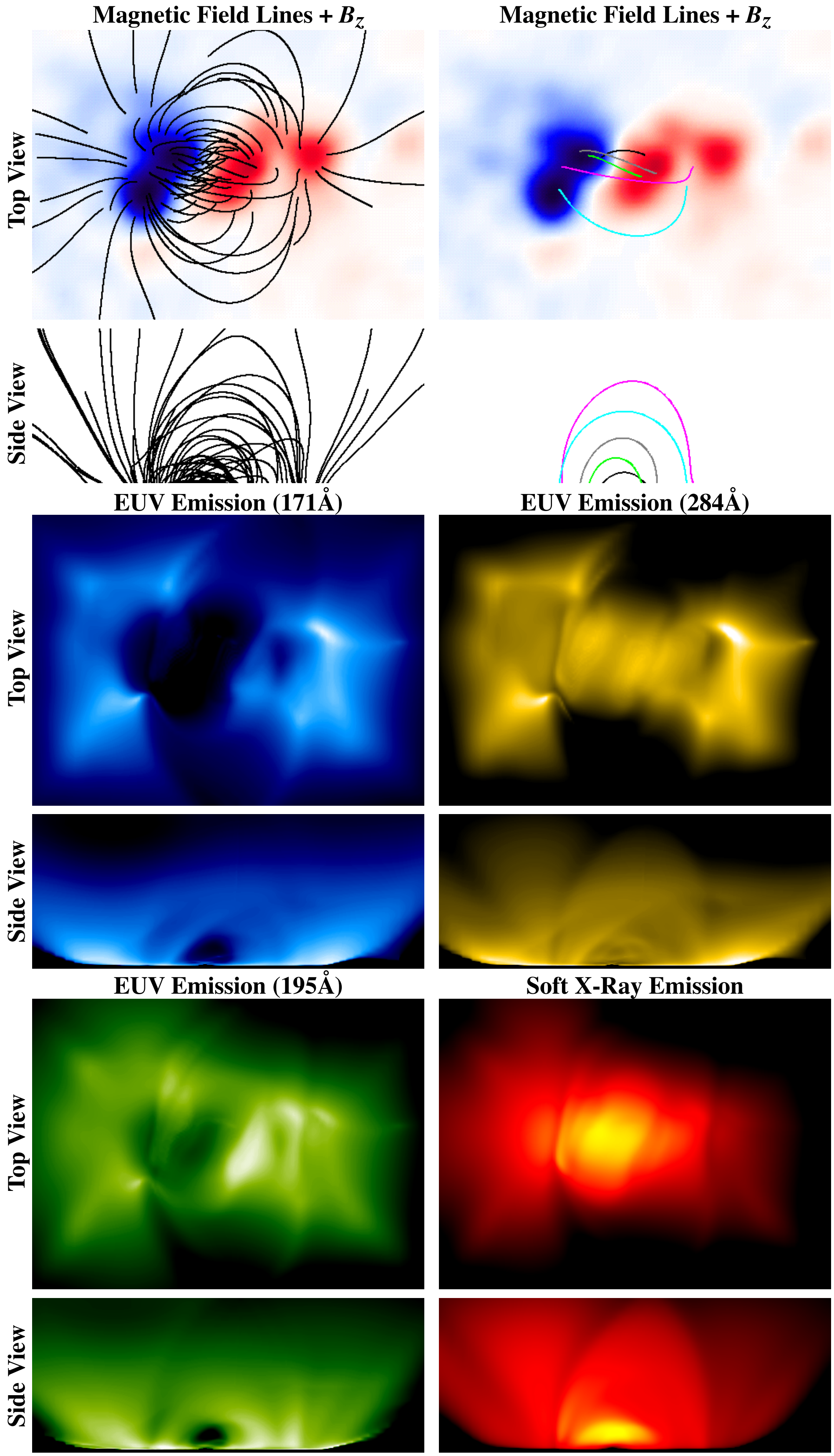


Figure 1. Modeling the magnetic and thermal structure of an active region on August 29, 1996. A Kitt Peak magnetogram is used to specify the normal component of the magnetic field. A twist is applied to the field, and the steady state is calculated for a given coronal heating distribution. The temperate and density structure shows that the transition region height varies in different parts of the active region.



Magnetic Field Lines + B_z
Magnetic Field Lines + B_z
Top View
Side View
EUV Emission (171Å)
EUV Emission (284Å)
Top View
Side View
EUV Emission (195Å)
Soft X-Ray Emission
Top View
Side View

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Step 5: Set The Boundary Conditions

Confirm selection of Carrington Rotation based on available data

Rotation: 2007 Start: 08/29/2003 End: 09/26/2003

Select coronal base temperature and density

Coronal base temperature : 1.6 x 10^6 [K]

Coronal base density : 2 x 10^8 [particles cm^{-3}]
(density range: (1.0 - 4.0) x 10^8 [particles cm^{-3}])

Select filter parameters for magnetogram data

Selected simulation grid: **low-resolution (61x51x32)**
Recommended maximum longitudinal mode number: 6
Recommended number of latitude filter passes: 3
Recommendations and ranges for filter parameterns are based on grid resolution.

Maximum longitudinal mode number (Range: 1 - 6) 6

Number of latitude filter passes (at least 2): 3

Continue

Selected Boundary Conditions

Carrington Rotation: 2007

Plasma Parameters:

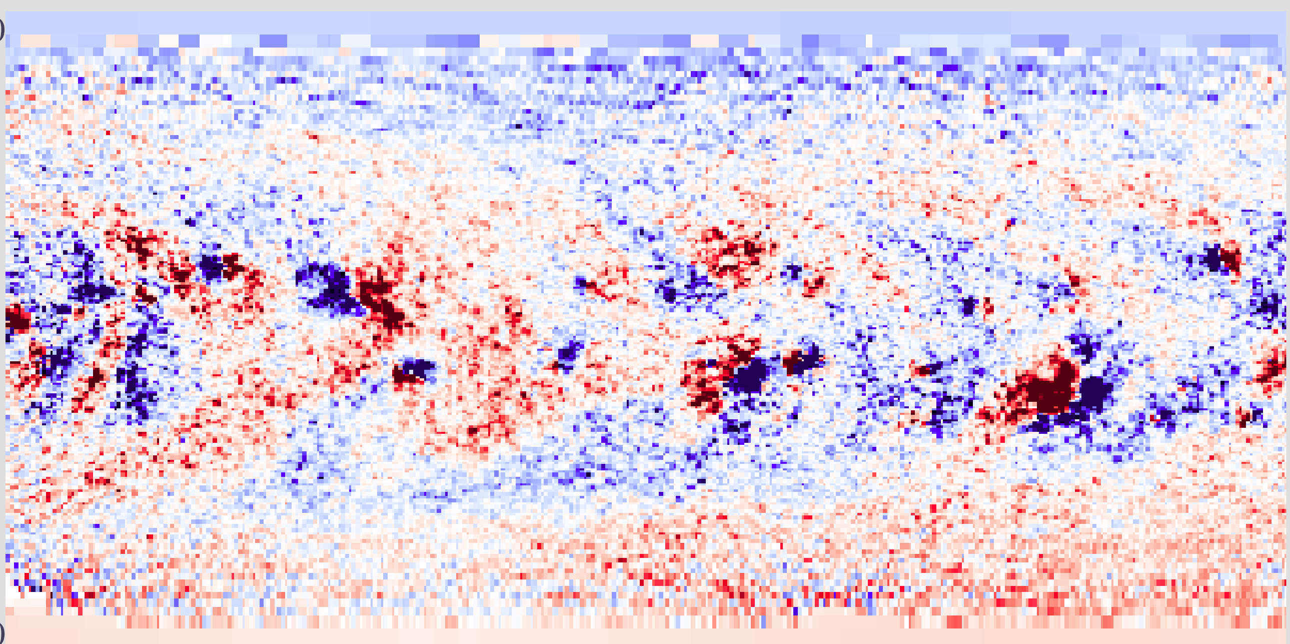
Coronal Base Temperature: 1.6 [million K]
Coronal Base Density: 2 x 10^8 [particles cm^{-3}]

Radial Magnetic Field [Gauss]:

Maximum for B_r: 50 **Gauss**

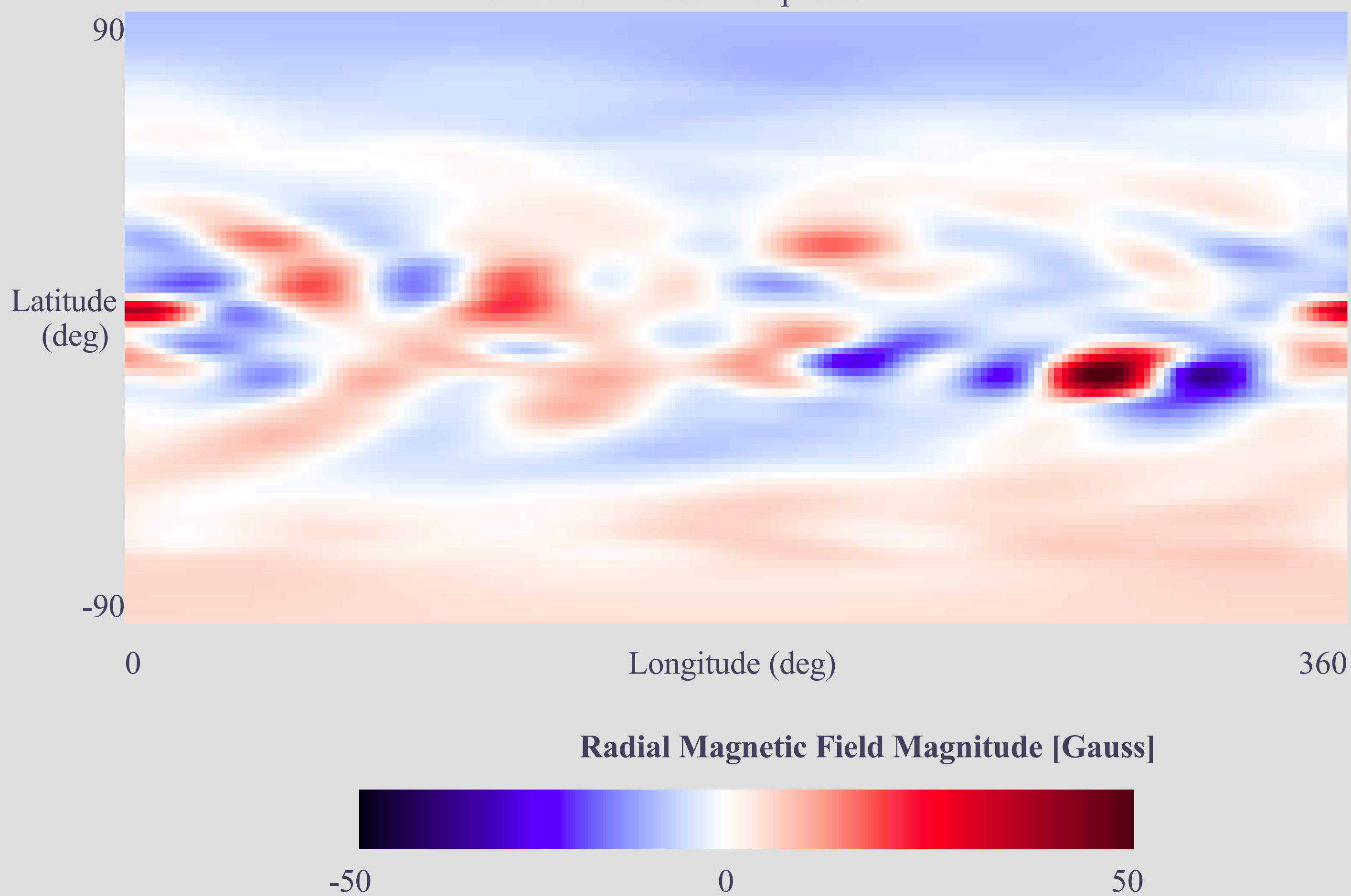
Change scale range for radial magnetic field maps

Raw Kitt Peak Magnetogram



Filtered Kitt Peak Magnetogram

Filter Parameters:
Maximum longitudinal mode number: 6
Number of latitude filter passes: 2



Step 6: Set Numerical Simulation Parameters

Selected grid: low-resolution (61x51x32), Radial grid range: 1 - 20 [solar radii]
Lundquist number (Range: 100 - 2000) : 1000
Hydrodynamic viscosity (> 0.05): 0.05

Output time interval: 40 hours
Minimum output time interval is 5 hours

Continue

Zoran_Mikic_090803_SH_1

Title/Introduction: Test run to validate the submission procedure. Please disregard the output of this run.

Key Word: Test run

Model Type: Solar/Heliosphere
Model: MAS
Input Type: Time-Independent
Carrington Rotation
Coronal Base Density: 2.2
Coronal Base Temperature: 1.8
Simulation Grid: low-resolution (61x51x32)
Lundquist Number: 1000
Viscosity: 0.05

- View Magnetogram input data
- Read Input file
- Read output file *occmc*
- Plot output file *hccmc*
- Plot output file *qccmc*
- Plot output file *vccmc*

3D Simulation Results: Model: MAS Run: Zoran_Mikic_090803, CR=2005, T=1.8e6 K, N=2.2e8/cc

This is the web interface for the visualization of results of a three-dimensional simulation of the Sun's environment.

Please review the default selections below and make your changes.

To start the graphics program click the *Update Plot* button. The resulting image will be displayed at this location of the page.

Should the result be a black image, then the graphics program encountered a programming error. Please report the set of input parameters used.

[Update Plot] *Update Plot* will update (generate) the plot with the chosen time and plot parameters below.
This will take some time (typically 10-30s) as data is read in and processed.

Choose data time: 40:00:28

- or -

Change time by moving -1 output steps

Plot Options:

- [x] **Exclude region around the Sun** up to 1 R_S
- [x] **Allow variable plot image size** (2D plots, aspect ratio (ratio dx/dy of plot) between **0.3** and **4**)
- [ ] **Show simulation grid** (disabled with `3D-Surface`)
- [ ] **Interpolate data onto equidistant grid** (available with `3D-Surface` and `Vector`; recommended for plots with `Vector`)

Choose Plot Mode: ColorContour

Choose quantity to be displayed (some **Plot Modes** require up to three choices)
Q 1: N Q 2: N Q 3: N

Plot Options for selected Plot Modes:

3D-Surface, 3D-Flowlines View angles:
AX [-90..90]: 30
AZ [0..180]: 30

Color Contour: [ ] Use Grayscale
[ ] Lock color range: (Log scale: use original values > 0)
Min.: -1

3D-Flowlines: flowline start positions
Choose Flowline Setup Mode: predefined in 3D (V,B,other)
user-defined flowline start positions:
Radius r: 9.0, 9.5, 10.0, 10.5, 11.0, 11.5
Lon. p: 0, 0, 0, 0, 0,0
Lat. t: 0, 0, 0, 0, 0,0

Max.: 1

☐ Log scale (N/Rho, En. P, most fluxes F...)

Contour:

☐ show values with contour levels

Vector: length of arrows: 1.0

Choose Plot Area:

All **Plot Modes** except **Line Plot**: Select lower left corner of plot area on the left, and the upper right corner on the right.

Line Plot: Select start point of line on the left, the end point on the right.

Radius r_1	Radius r_2	
1	20	Range: 1 ... 20 R_S
Lon. p_1	Lon. p_2	
0	360	Range: 0 ... 360 deg.
Lat. t_1 -90	Lat. t_2 90	Range: -90 ... 90 deg.

Choose Cut Plane:

Radius r=constant ○ 10.5

Lon. p=constant ● 180

Lat. t=constant ○ 0

Reset Form *Reset Form* will reset changes to the defaults specified by the previous run of this script.

Update Plot *Update Plot* will update (generate) the plot with the chosen time and plot parameters above.

☐ **List Data** (check to get any of the following outputs):

○ At positions specified: enter positions in Radius r, Lon. p, Lat. t, (within the allowed range) as comma-separated lists.

Radius r positions:

0.0, 0.0, 0.0

Lon. p positions:

5.0,7.5,10.0

Lat. t positions:

0.2,0.3,0.4

● **List Data From Plot:**

- **2D plots** (Contour, Vector, ...): equidistant 31x31-element grid in selected cut plane
- **LinePlot**: data along line plotted,
- **3D-Flowlines** start and end points of flow lines with topology and exit status of line segment tracings.

Curator: Dr. Lutz Rastätter
Authorizing NASA Official: Dr. Michael Hesse

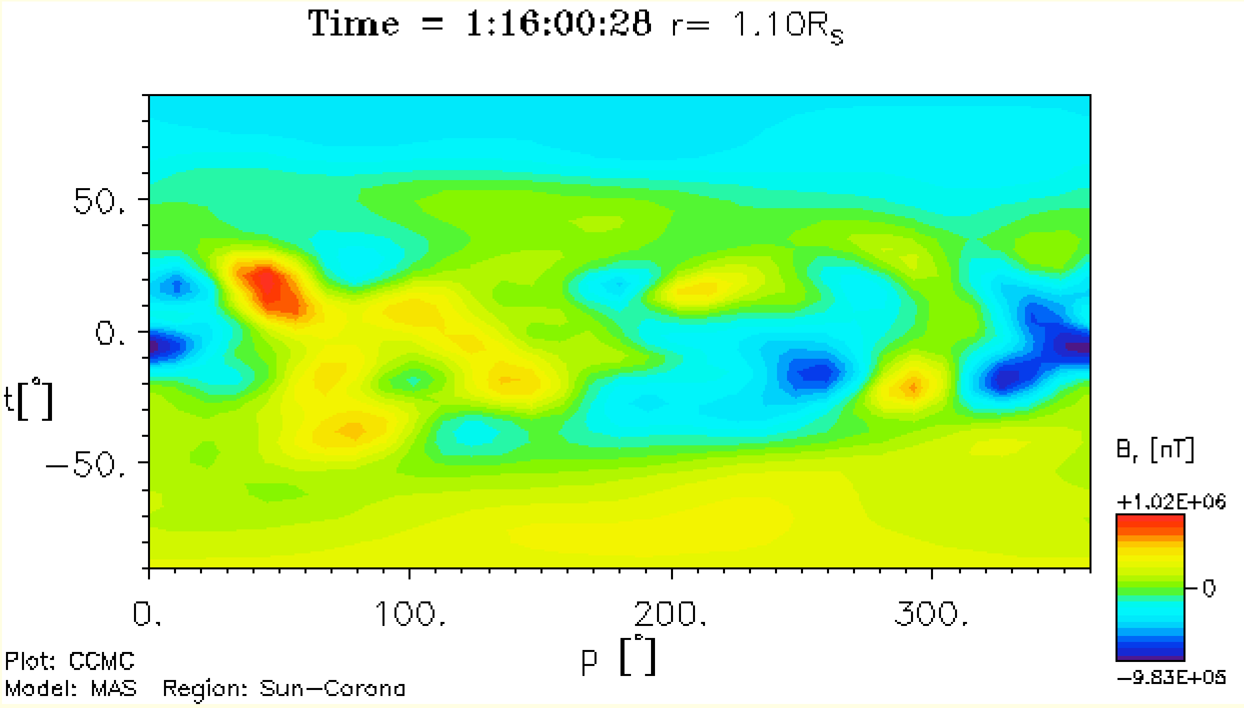


Figure: Simulation of the Solar Corona using Carrington rotation (CR) and coronal base temperature T.
Model: MAS
Run: Zoran_Mikic_090803, CR=2005, T=1.8e6 K, N=2.2e8/cc

To track usage for our government sponsors, we ask that you notify CCMC staff whenever you use CCMC results in a scientific publication or presentation. Thank you.

Update Plot *Update Plot* will update (generate) the plot with the chosen time and plot parameters below.
This will take some time (typically 10-30s) as data is read in and processed.

Choose data time:
40:00:28
- or -
Change time by moving
-1 output steps

Plot Options:

Exclude region around the Sun up to 1 R_S

Allow variable plot image size (2D plots, aspect ratio (ratio dx/dy of plot) between **0.3** and **4**)

Show simulation grid (disabled with `3D-Surface`)

Interpolate data onto equidistant grid (available with `3D-Surface` and `Vector`; recommended for plots with `Vector`)

Choose Plot Mode:
ColorContour

Choose quantity to be displayed (some **Plot Modes** require up to three choices)
Q 1: B_r Q 2: N Q 3: N

Plot **3D-Surface,** **3D-Flowlines:** flowline start positions

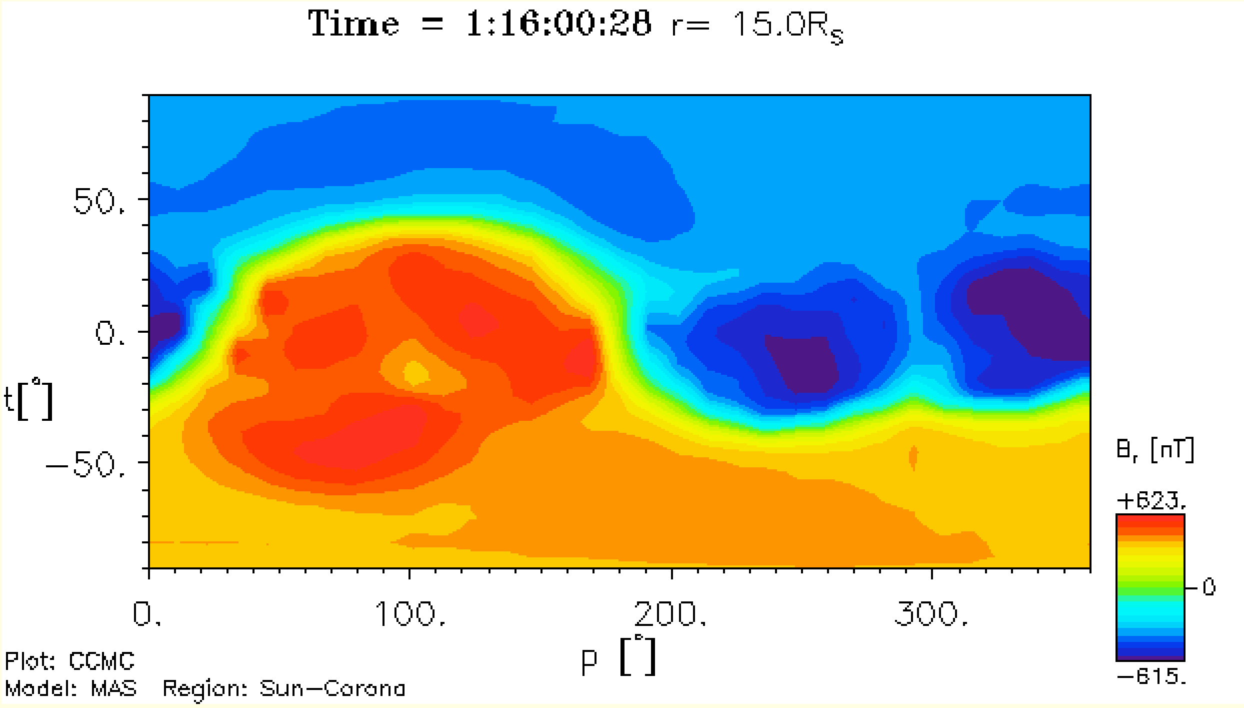


Figure: Simulation of the Solar Corona using Carrington rotation (CR) and coronal base temperature T.
Model: MAS
Run: Zoran_Mikic_090803, CR=2005, T=1.8e6 K, N=2.2e8/cc

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Choose data time: 40:00:28

- or -

Change time by moving -1 output steps

Plot Options:

- **Exclude region around the Sun** up to 1 R_S
- **Allow variable plot image size** (2D plots, aspect ratio (ratio dx/dy of plot) between **0.3** and **4**)
- **Show simulation grid** (disabled with `3D-Surface`)
- **Interpolate data onto equidistant grid** (available with `3D-Surface` and `Vector`; recommended for plots with `Vector`)

Choose Plot Mode: ColorContour

Choose quantity to be displayed (some **Plot Modes** require up to three choices)
Q 1: B_r Q 2: N Q 3: N

Plot **3D-Surface,** **3D-Flowlines:** flowline start positions

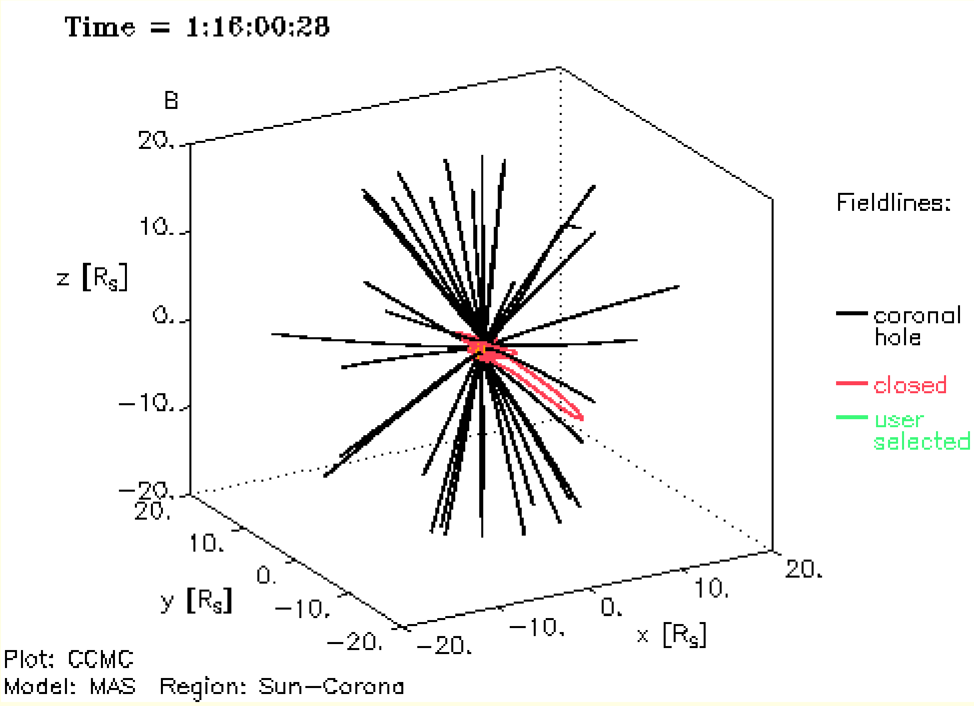

Figure: Simulation of the Solar Corona using Carrington rotation (CR) and coronal base temperature T.
Model: MAS
Run: Zoran_Mikic_090803, CR=2005, T=1.8e6 K, N=2.2e8/cc

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Update Plot *Update Plot* will update (generate) the plot with the chosen time and plot parameters below.
This will take some time (typically 10-30s) as data is read in and processed.

Choose data time: 40:00:28
- or -
Change time by moving -1 output steps

Plot Options:

- [x] **Exclude region around the Sun** up to 1 Rs
- [x] **Allow variable plot image size** (2D plots, aspect ratio (ratio dx/dy of plot) between **0.3** and **4**)
- [ ] **Show simulation grid** (disabled with `3D-Surface`)
- [ ] **Interpolate data onto equidistant grid** (available with `3D-Surface` and `Vector`; recommended for plots with `Vector`)

Choose Plot Mode: 3D-Flowlines

Choose quantity to be displayed (some **Plot Modes** require up to three choices)
Q 1: B_r Q 2: B_t Q 3: B_p

Plot **3D-Surface,** **3D-Flowlines:** flowline start positions

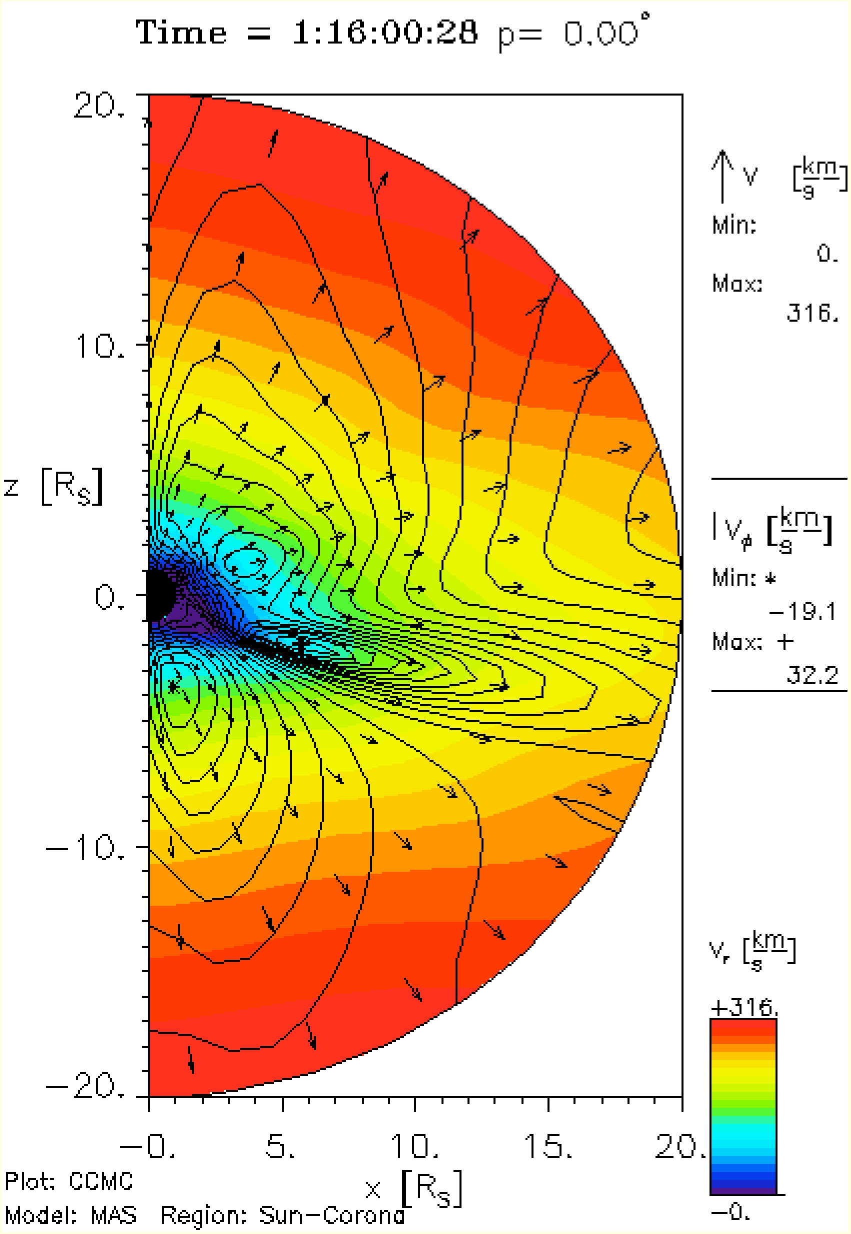


Figure: Simulation of the Solar Corona using Carrington rotation (CR) and coronal base temperature T.
Model: MAS
Run: Zoran_Mikic_090803, CR=2005, T=1.8e6 K, N=2.2e8/cc

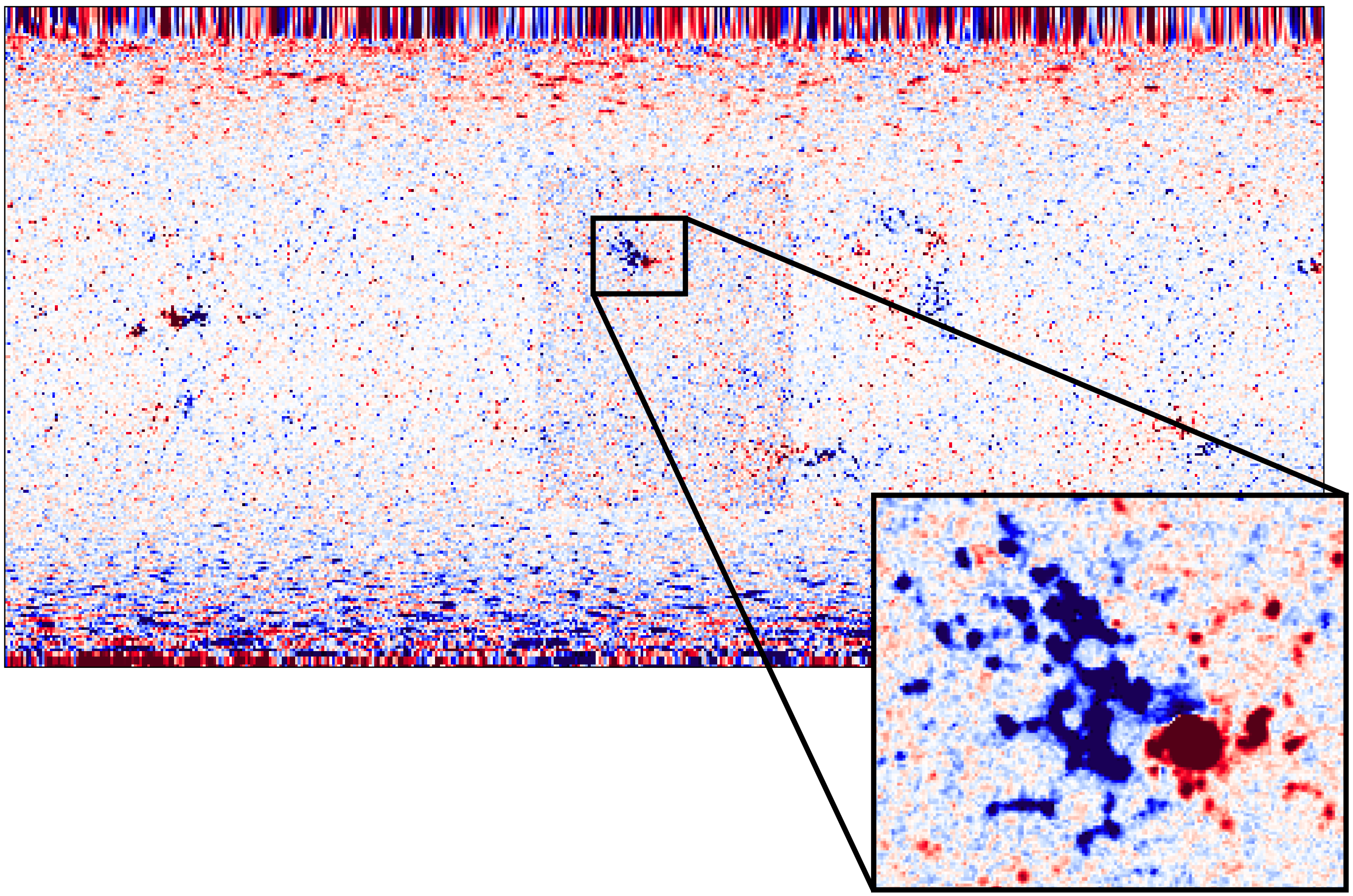
To track usage for our government sponsors, we ask that you notify CCMC staff whenever you use CCMC results in a scientific publication or presentation. Thank you.

Update Plot *Update Plot* will update (generate) the plot with the chosen time and plot parameters below.
This will take some time (typically 10-30s) as data is read in and processed.

Case 5

- MDI magnetogram on May 11, 1997 (courtesy of Phil Scherrer and Yang Liu)
- B ~ ??? G (N pole), ??? G (S pole)
- B ~ 2000 G (active region) [raw]

B_r at $r = R_o$



CASE 5

- MDI magnetogram on May 11, 1997 (courtesy of Phil Scherrer and Yang Liu)
- $B \sim 20$ G (N pole), 30 G (S pole)
- $B \sim 1000$ G (active region) [filtered]

B_r at $r = R_o$