Active Region Evolution

An LWS TR&T Strategic Capability Model

Peter MacNeice

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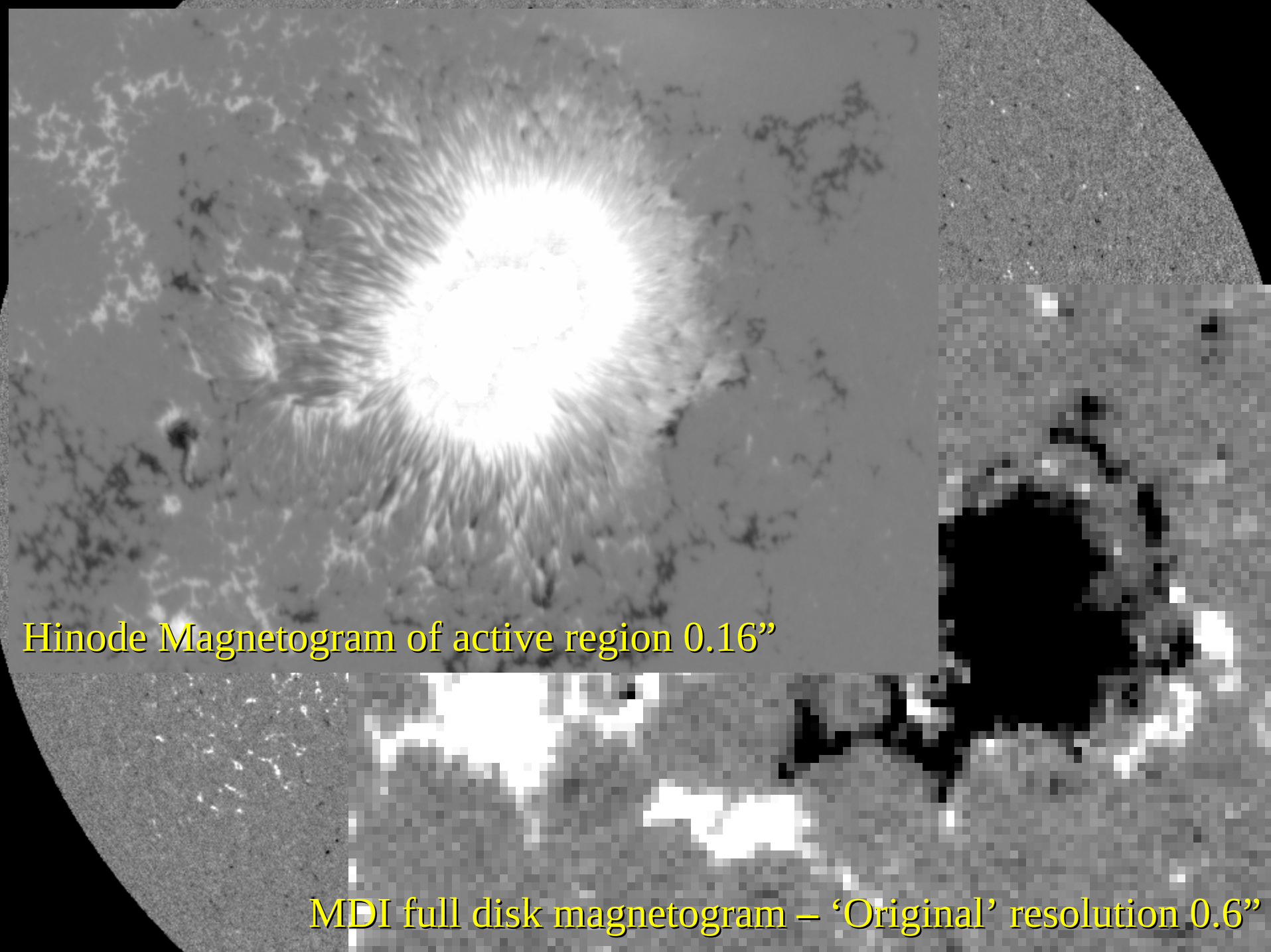
Objective

- To develop a community model to aid in understanding the structure and modeling the slow evolution of solar active regions
  - Focus is still very much on the coronal field topology
  - Not a model of explosive events!
- Why now? - Convergence of 3 factors
  - New vector magnetogram data sources
  - Maturity of models – at least for upper chromosphere thru corona!
  - Better computers
- Reasonable expectation to make a significant impact for scientific RoR - not clear for operations !


Hinode Magnetogram of active region 0.16”
MDI full disk magnetogram – ‘Original’ resolution 0.6”

NRA Essential Features

- Use vector magnetic fields
- Find physically consistent flow/fields from vector magnetograms for time dependent (quasi-steady) magnetic field evolution, including flux emergence/cancellation and apparent shearing motions
- Determine the 3D vector magnetic field and electric currents of a complex active region over as large a scale as possible
- Include the capability to interface with global coronal-heliospheric field models
- Provide user friendly interfaces and GUI for runs on demand by the general research community, including capability for zooming in on small portions of a simulation domain, and ability to analyze magnetic topology
- Provide the flexibility for quick turn-around runs
- Working version to be delivered to CCMC within 3 years; final production version delivered within 5 years.

NRA Desirable Features

- Include the ability to incorporate, as input, magnetic field observations from different heights in the solar atmosphere
- Include the ability to incorporate as input, photospheric velocity field data (?)
- Include the ability to incorporate as input coronal imaging data
- Allow for a variety of user-selectable field determination methods – ie multiple models

A Break With The Past

- Current community models use synoptic magnetograms – static
- Before - Model character defined by data limitations
- Now – model character dictates the magnetogram spatial and temporal resolution
- General Requirement : Need to be able to provide vector ***B*** at any surface point and any time during the run.

Critical Elements

Quality of model coronal fields critically dependent on two elements

1. The quality of the magnetogram and surface flow inputs
   - Magnetogram synthesis
2. How these inputs imprint themselves on the upper chromosphere
   - Nobody really knows – So we have kept this element of our design as modular and flexible as possible
     - The bleeding edge is RADMHD(Abbett 2007) – Is it mature and robust enough for community modeling in the next 5 years?
     - My bet is semi-empirical models of this layer will give best results for many years
   - I anticipate this being one of the main science questions that this model's users will address
   - Could bypass this constraint by using chromospheric magnetograms
     - My bet is good chromospheric vector magnetogram data will arrive before 'useable' physics based models of the photosphere/upper chromosphere connection

Design

- Modular
- 8 components
  - AR database Tool
  - Grid Generation Tool
  - Global Magnetogram Generation Tool
  - Surface solution Consistency Tool
  - NLFFF and NLNFFF codes
  - 3D adaptively refining MHD code
  - Field Topology analyser
  - GUI
- Very compact team (10 people)
  - Not a CCMC funded effort!
  - Personnel from Drexel, NRL, MaxPlanck, UMBC, NASA

} ?

Design (contd)

- MHD model should be global
  - Will use AMR on unstructured grid
  - Will use NLFFF and NL**N**FFF solutions as pre-conditioner
  - Will migrate from explicit to implicit algorithm
- Use DAVE to determine driving surface flows for MHD
  - Unique property that data uncertainty can be factored into the BC analysis
- Use Kameleon for file formatting
  - Each component will have a write routine casting its data in Kameleon format
  - Each will use a general Kameleon read routine
  - More about this on Thursday.

Principal Deliverables

- Fully functional beta package delivered by end of year 3
- Optimized package delivered by end of year 5
- In addition we have a number of annual deliverables in the SOW - including hosting community testing workshops

Force-Free Models

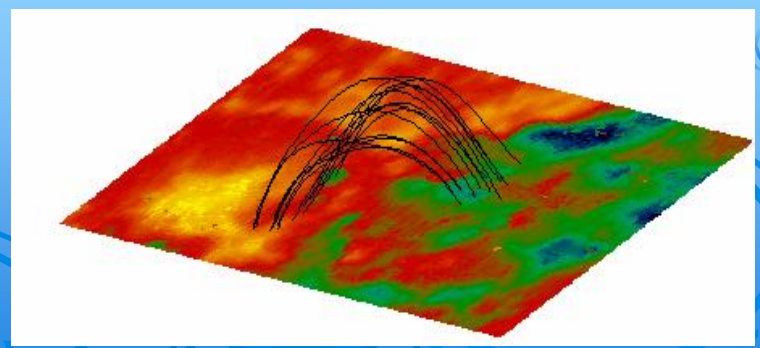
- NLFFF and NL**N**FFF models of Wiegelmann
- NLFFF Implements Wheatland's minimization technique

$$I = \alpha \nabla \cdot B + \beta J \times B$$

- NL**N**FFF minimizes

$$I = \alpha \nabla \cdot B + \beta \left(J \times B - \nabla p + \rho g \right)$$

- NL**N**FFF departures from force-free driven by coronal imaging analysis
- Proven capability – NLFFF selected for use in data processing for SDO
- Principal developments
  - test spherical coordinate version
  - Implement unstructured grid version
  - Add *v*.grad *v* term to integrand



Non-linear force-free reconstruction

MHD Model

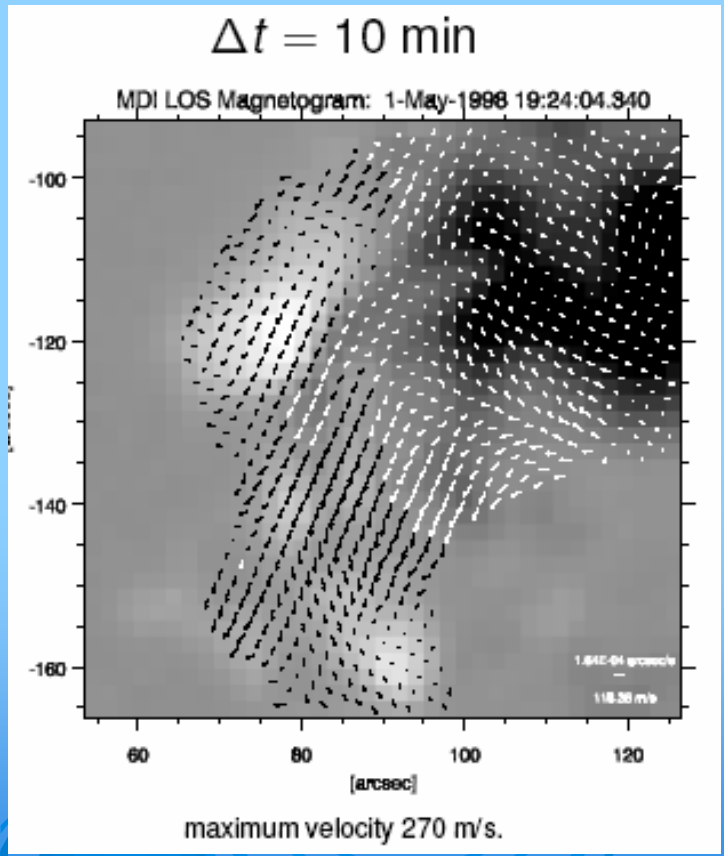
- 3D Global Finite Volume MHD – Spicer (2007)
- Unstructured Grid with AMR
  - vital because of requirement to refine at a spherical inner boundary
- Equations solved in conservative cartesian form
- High Order Godonov (2^{nd} order time and space)
  - may even support a Godonov based force-free algorithm
- div $\boldsymbol{B} = 0$ to round-off
- Both radial boundaries can be treated as separate 2D computational domains
  - eg easy to compute 2D surface advection of flux
- Anisotropic thermal conduction, optically thin radiation – in testing
- Parallel
- Currently explicit – developing implicit version for fast turnaround runs

Magnetogram Synthesis Tool

- This is a model (or class of models) in its own right
  - Combine data from multiple sources – LOS and vector, full disk and limited fov, high and low cadences
  - Basically an ($\boldsymbol{x}$,t) interpolation problem on a spherical surface
  - Apply appropriate physical constraints
    - Eliminate monopoles
    - Avoid spurious current densities at joins

Magnetogram Synthesis Tool (contd)

- To generate surface flows which are statistically consistent with the magnetogram data and induction equation for MHD solver
  - Using DAVE (Differential Affine Velocity Estimator - Schuck 2006)
    - Extension of LCT
    - Permits image data to expand, contract and rotate from frame to frame
    - Minimizes deviations from induction equation while allowing for noise in the data
    - Can switch to tracking temperature proxies where field data is too weak to use
    - Very fast (200 seconds for a 1024x1024 LOS image)



Magnetogram Synthesis Tool (contd)

- Such a compelling idea, we expanded the idea for AISRP – also selected (with funding reduced because of overlap)
- LWS proposal described a tool specifically designed for this AR model
- AISRP version is much more general
- Two distinct processing layers
  - Lightweight – pulldown menu, commonly needed simple processing ie monopole subtraction, basic current reduction at joins etc
  - Heavyweight – an interface to support calling any 3rd party model to process the data
    - eg how would you want to combine photospheric and chromospheric magnetograms with perhaps constraint from other image sources?
- More info on this in Thursday's session

Surface Consistency Tool

The photosphere/corona connection

- Anticipate that this will eventually be a 3D model in its own right.
- Responsible for generating inner radial boundary conditions for NLFFF, NL**N**FFF and MHD codes.

- For NLFFF
  - Photosphere is not force-free
  - Modify the more uncertain transverse component of vector fields to enforce force-free condition
  - Add chromospheric Hα fibril info in pre-processing - helps further minimize div $\boldsymbol{B}$ and $\boldsymbol{j} \times \boldsymbol{B}$
  - Add chromospheric LOS magnetogram to supplement Hα fibril info

Surface Consistency Tool

- For MHD
  - Zeroth order – do nothing - apply photospheric fields+flows as though at the base of the corona
    - More realistic for lower resolution data
    - For higher resolution data may have to dumb down resolution
  - Pre-conditioning with NL**N**FFF - need some model of shear flows in thin layer of NL**N**FFF to avoid model inconsistencies
  - After that ? - Keeping our options open !
    - Canopy type models ?
    - Schrijver and Title type model ?
    - Magnetic charge topology models?

Status

- Had kick-off meeting at Goddard last week
- Plan to have Version 0.1 of DAVE, NLFFF and MHD codes in SubVersion repository by end of November
- Upgraded DAVE to use vector data - now in testing
- NLFFF
  - Tested with 5 different vector magnetogram sources
  - Testing spherical grid version for both local and global runs
    - Yin-Yang grid to minimize polar numerical stability constraint
  - Working on first AR time series - Thalmann, Fall AGU
- MHD code
  - adding anisotropic conduction for physically motivated solar wind - guided by extensive experience with our 2.5D code
  - Optimizing parallel grid generator

Milestones

First major milestone overdue

Haven’t yet come up with a snappy acronym !

Thank You