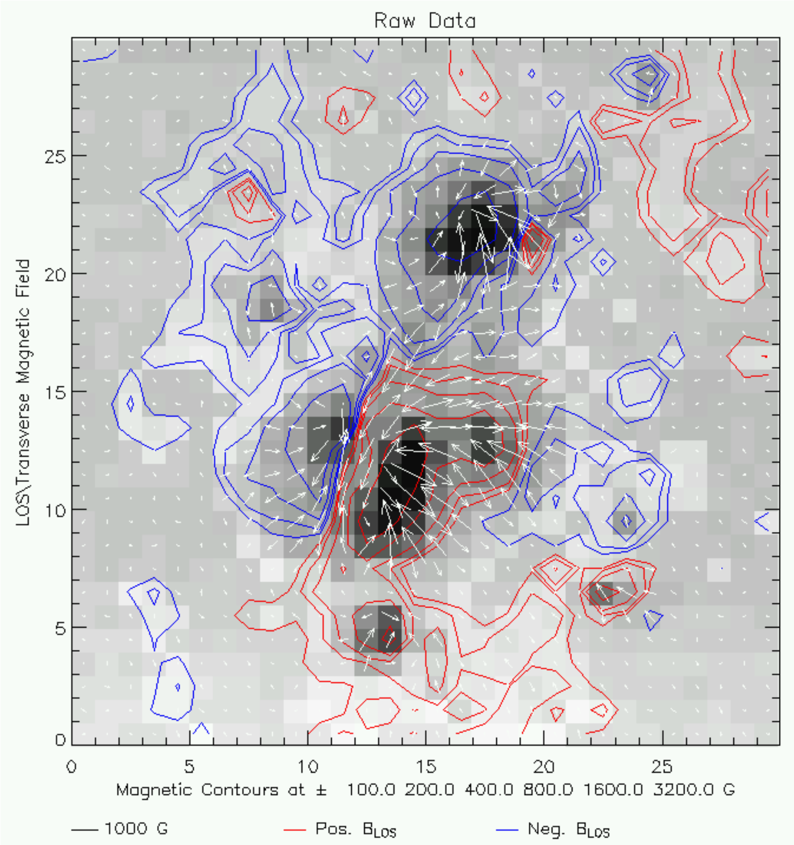
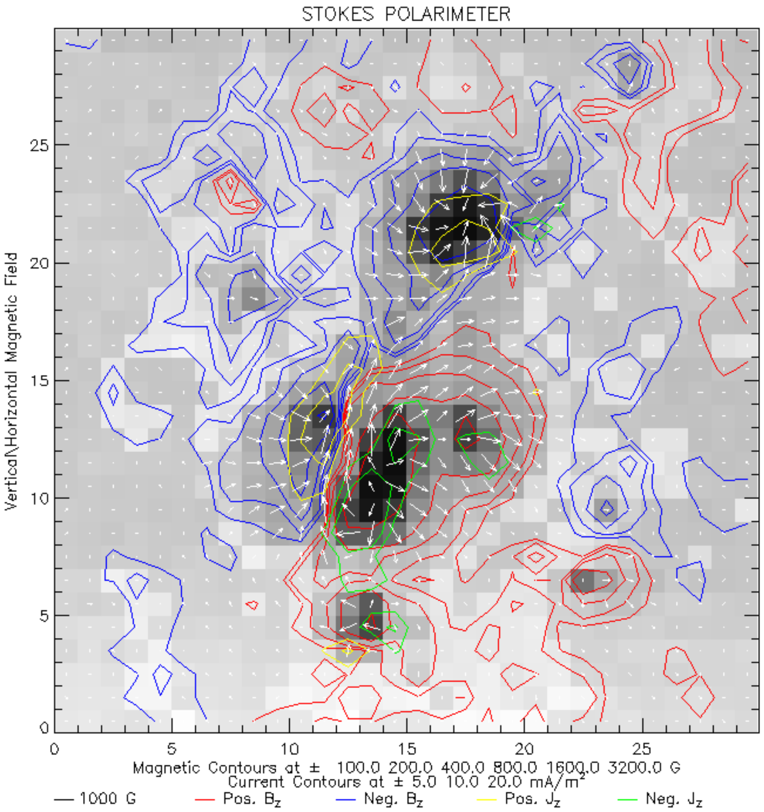
Resolving the 180 Degree Ambiguity in HMI Vector Magnetic Fields

T. Metcalf

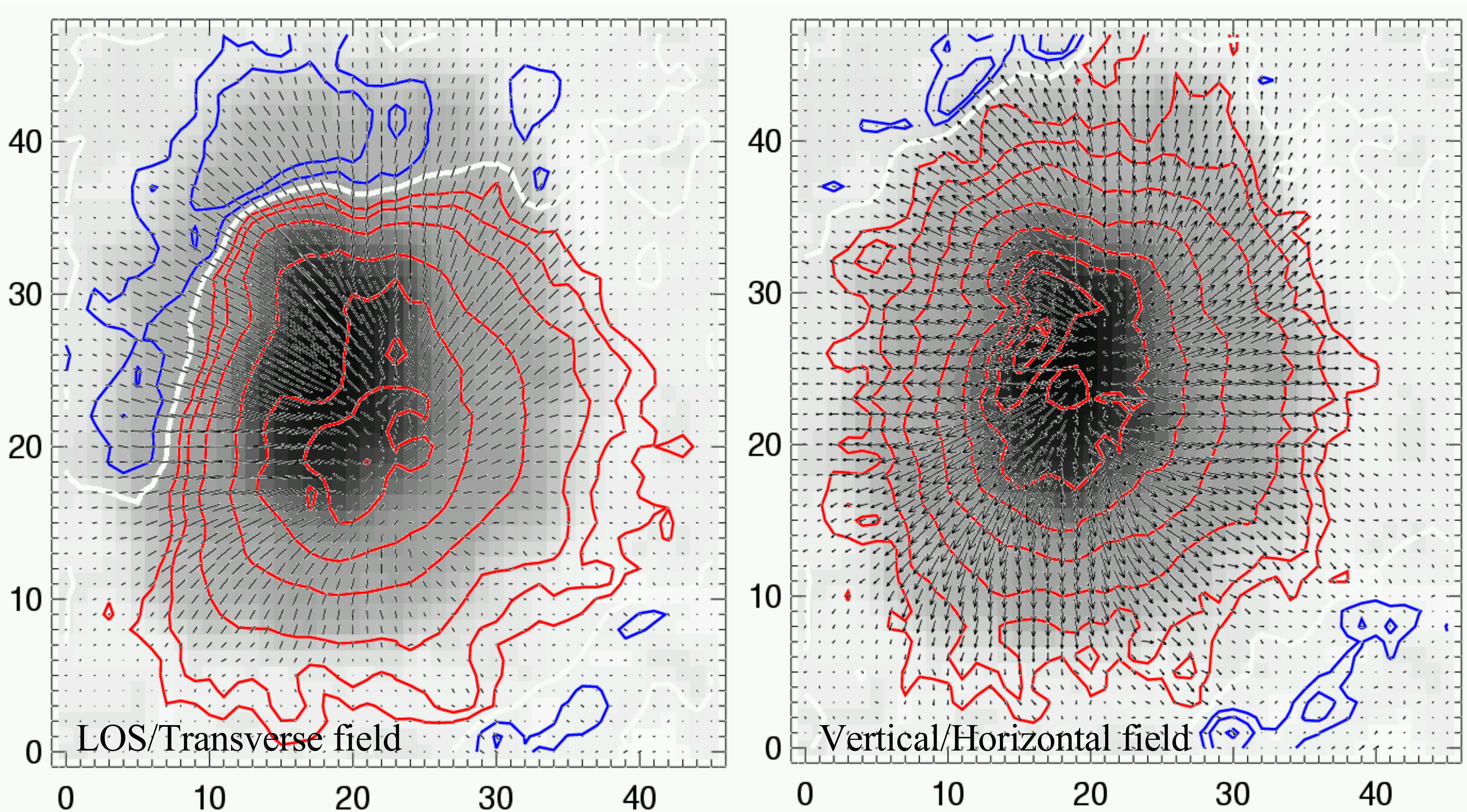
The Transverse field is Ambiguous by 180 Deg

This ambiguity must be resolved before analysis.





Ambiguity Resolution is Required to Compute Correct Neutral Lines



How do we resolve the ambiguity?

- There are a number of ways to resolve the ambiguity but, as a practical matter, this is most difficult for the most “interesting” datasets while easy for “uninteresting” datasets.
- All methods make some a priori assumptions about what the field should look like, e.g. Potential, force free, minimum energy state, etc.
- With information on the vertical structure of the field, it is in principle possible to resolve the ambiguity without assumptions.
- Problems to bear in mind:
  - Noise in the vector field measurement.
  - Projection effects near the limb.
  - Speed of algorithms.

Where do we stand now?

- A workshop was held at HAO in Sept 2005. Many algorithms participated in a "shootout".

Table 1 Summary of Algorithms.

Method	quantity minimized	minimization scheme
Acute Angle	$\lvert\theta_o - \theta_e\rvert$	local
Large Scale Potential	$\lvert\theta_o - \theta_e\rvert$	scale variation
USM	$\lvert\theta_o - \theta_e - \Delta\theta_{mp}\rvert$	local
Dissipation of Magnetic Pressure	$\partial B^2/\partial z$	local
Minimum Structure	$\omega_s \partial B/\partial z + \omega_p \lvert J_{2_z}\rvert$	local+smoothing
NPFC	$\lvert J_z\rvert$	iterative
Pseudo-Current	$\int d^2 a J_z^2$	conjugate gradient
UH Iterative	$\int d^2 a J_z^2$	iterative
Minimum Energy	$(\lvert J\rvert + \lvert\nabla \cdot B\rvert)^2$	simulated annealing
AZAM	angle between neighboring pixels	interactive

Noise-Free Test Cases

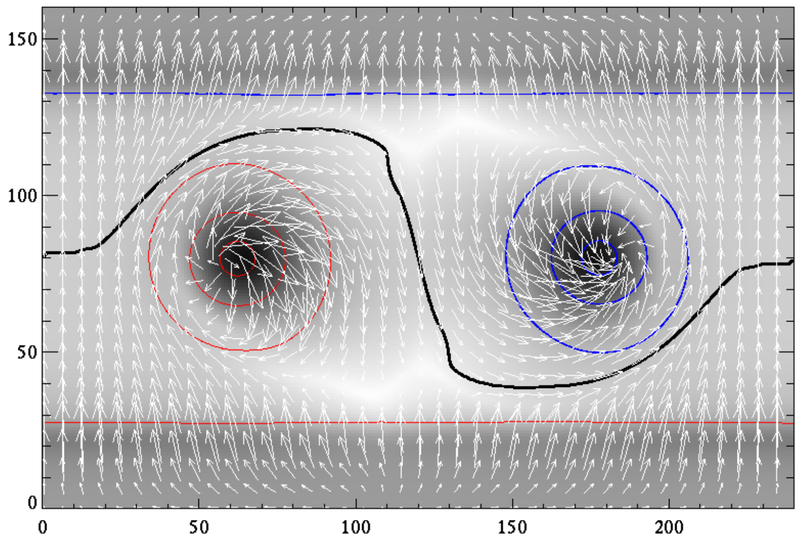
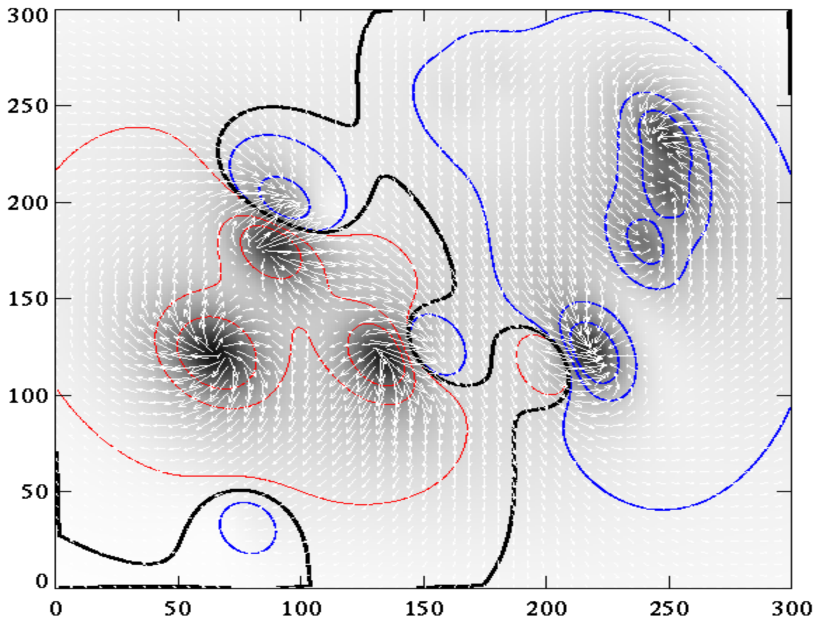


Fig. 1 Vector magnetic field at $z = 0.006L$ from the numerical simulation of Fan and Gibson



- Bald patch neutral line
- Not force free
- Strong field at edges
- At disk center

- Bald patch neutral lines
- force free
- Not flux balanced
- Not at disk center

Workshop Results

Solution	Fluxtube and Arcade				Multi-Pole at $\mu \neq 1.0$			
	$\mathcal{M}_{\text{area}}$	$\mathcal{M}_{\text{flux}}$	$\mathcal{M}_{B_h(s)}$	$\mathcal{M}_{J_z}$	$\mathcal{M}_{\text{area}}$	$\mathcal{M}_{\text{flux}}$	$\mathcal{M}_{B_h(s)}$	$\mathcal{M}_{J_z}$
Acute Angle (potential, FFT)								
NJP (Ju Jing)	0.67	0.49	0.92	-0.07	0.76	0.85	0.87	0.10
YLP (Y. Liu)	0.64	0.54	0.90	-0.08	0.82	0.86	0.88	0.08
KLP (K. Leka)	0.75	0.69	0.94	0.25	0.64	0.90	0.73	0.20
Acute Angle (potential, Greens Func.)								
BBP (V. Yurchyshyn)	0.72	0.65	0.92	0.04	0.78	0.88	0.90	0.25
JLP (Jing Li)	0.70	0.64	0.90	-0.01	0.71	0.81	0.83	0.13
Acute Angle (LFFF)								
HSO (H. N. Wang)	0.87	0.70	0.99	0.68	0.85	0.94	0.94	0.60
Large Scale Potential								
LSPM (A. Pevtsov)	0.69	0.53	0.89	-0.84	0.69	0.89	0.74	-0.38
Uniform Shear Method								
USM (J. Jing)	0.69	0.59	0.68	-0.87	0.30	0.36	0.26	-1.17
Dissipation of Magnetic Pressure								
DMP (J. Li)	0.74	0.92	0.85	-0.77	0.67	0.79	0.76	-0.41
Minimum Structure								
MS (M. Georgoulis)	0.22	0.14	0.23	0.18	0.36	0.67	0.58	-0.29
Nonpotential Magnetic Field Calculation								
NPFC (M. Georgoulis, original)	0.70	0.62	0.92	0.02	0.70	0.90	0.83	-0.00
NPFC2 (M. Georgoulis, revised)	0.90	0.77	1.00	0.81	0.99	1.00	1.00	0.98
Pseudo-Current								
PCM (A. Gary)	0.78	0.49	0.98	0.54	0.77	0.82	0.82	0.40
UH Iterative								
UHIM (K. Leka)	0.97	0.91	1.00	0.88	0.97	0.99	1.00	0.97
Minimum Energy								
ME1 (T. Metcalf, original)	0.98	0.96	1.00	0.93	1.00	1.00	1.00	0.99
ME2 (T. Metcalf, non-linear)	1.00	0.99	1.00	0.97	1.00	1.00	1.00	1.00
AZAM								
AZAM (B. Lites)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acute Angle (conducting walls, FFT)								
TMC (T. Metcalf)	0.83	0.94	0.91	0.39	–	–	–	–

Compare results to Acute Angle. Is there value added?

All metrics should ideally be close to 1.0

Workshop Conclusions

- There *are* algorithms that resolved the ambiguity essentially perfectly. There is hope!
- The details of the algorithms are important. How are boundary conditions implemented? How are minimization schemes implemented? Etc.
- Flux imbalance is important. HMI will cure this to a large extent, but the algorithms may need to be recast in spherical coordinates: field connectivity can be on large scales.
- The most successful algorithms minimize some combination of the electric current (smoothness) and $\nabla \cdot \boldsymbol{B} = 0$ (physical contraint). Both seem to be necessary.

Where do we go from here?

- There will be a second workshop, probably in November 2006. Now that we understand how the algorithms behave, the second workshop will:
  - Add test cases with noise. How robust are the algorithms?
  - Make quantitative speed comparisons between algorithms. Which are fast enough? How do they scale with the number of pixels?
  - Use a full disk model. How does global connectivity affect the results?
  - Try to include any other methods that were not included in the first workshop.

What do we need to implement ambiguity resolution for HMI?

- How often does a full ambiguity resolution need to be done?
- There will likely be more than one algorithm used.
  - A fast algorithm applied to the full disk data to get close.
  - A very accurate algorithm which can be applied to a more limited field-of-view as needed.
- The algorithms will very likely need to be reimplemented in spherical coordinates.
- A key ingredient for the most robust algorithms is the vertical gradient of the field. Indeed, just knowing the sign of $\frac{\partial B_{los}}{\partial los}$ is, in principle, enough. Can this be measured?
  - Nour-Eddine Raouafi and Juan Borrero are making progress with SOLIS data.
  - Chromospheric vector field data would be very useful to get multiple heights (GBO). Metcalf & Leka are making progress here.